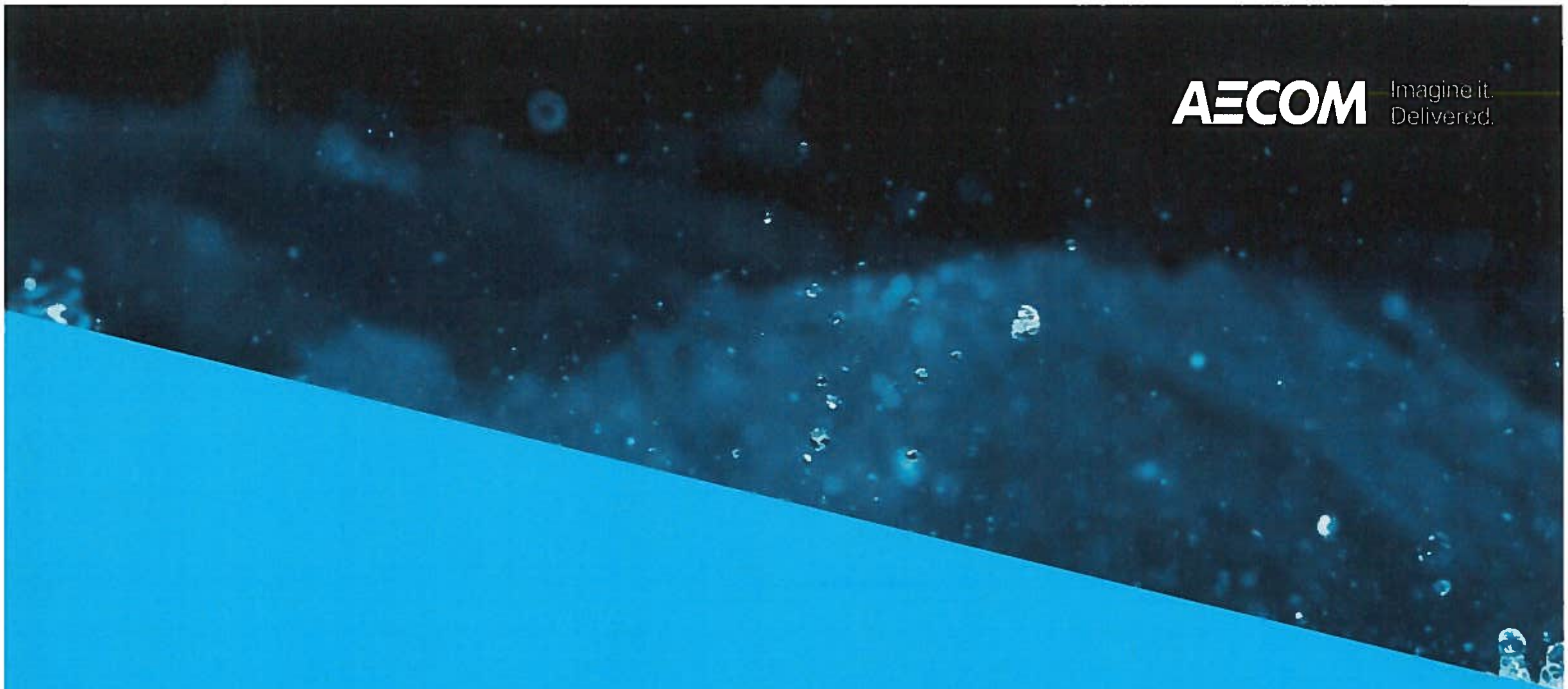

Water Demand and Supply Evaluation

FINAL REPORT

Town of Ipswich, MA

February 2019

Prepared for:

Town of Ipswich
272 High Street
Ipswich, MA 01938

Prepared by:

AECOM
250 Apollo Drive
Chelmsford, MA 01824

AECOM

Water Demand and Supply Evaluation

FINAL REPORT

Town of Ipswich, MA

COMMONWEALTH OF MASSACHUSETTS
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REGISTERED
PROFESSIONAL ENGINEER

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GLOSSARY

Acronyms and Abbreviations

ADD	Average day demand
ASR	Annual Statistical Report
BRP WS	Bureau of Resource Protection – Water Supply (DEP permit category)
DEP	Massachusetts Department of Environmental Protection
DCR	Department of Conservation and Recreation
gpm	US gallons per minute
gpm/ft	gallons per minute per foot of drawdown; an expression of well performance
GW	Groundwater
MassDOT	Massachusetts Department of Transportation
MDD	Maximum day demand
MEPA	Massachusetts Environmental Policy Act; the MEPA Unit is the clearinghouse for informing the public of upcoming projects that might impact the environment, and ruling on those projects.
MGD	Million Gallons Per Day
mg/L	milligram per liter; unit of concentration of a chemical in water
MMCL	Massachusetts Maximum Contaminant Level; drinking water standard, the maximum permissible level of a contaminant in drinking water
ND	not detected
NSA	New Source Approval; refers to the DEP process for testing and permitting new sources of groundwater supply
"the policy"	the Commonwealth's Policy for Developing Water Needs Forecasts
RESSIM	Reservoir Storage-Yield Computer Simulation Model
RGPCD	residential gallons per capita per day
SMCL	Massachusetts Secondary Maximum Contaminant Level, drinking water standard, requisite to protect public welfare
SW	Surface Water
UAW	Unaccounted for Water
USGS	United States Geologic Survey
VOC	Volatile Organic Compounds
WMA	Water Management Act; Massachusetts law intended to equitably allocate water resources.

WRC	Water Resources Commission
WTP	Water treatment plant

Selected Technical Terms

Aquifer - A natural geologic unit that is capable of storing and delivering a sufficient quantity of water to a well, e.g., a sand-and-gravel aquifer or fractured-bedrock aquifer

Bathymetric Survey: the study or measurement of the depth of water in an ocean, sea, or lake

Bedrock - The continuous unit of rock that underlies the earth's surface

Brackish Groundwater - Brackish groundwater is water located under the surface which is more saline than freshwater but less saline than seawater. This kind of water can be found in wetlands or deep aquifers. Brackish water is defined as groundwater with a concentration of total dissolved solids (TDS) in a range from 1000 to 10000 mg/L.

Confined Aquifer - An aquifer that is covered by a natural geologic layer, such as clay, that does not transmit water readily

Confining Layer - A natural geologic layer, such as clay, that covers a confined aquifer

Failure: A reservoir failure occurs when a reservoir is unable to provide sufficient water to meet demand.

Firm Yield - The term used when referring to the capacity or yield of a reservoir or reservoir system.

Groundwater discharge or seepage – Groundwater that discharges naturally from an aquifer to a stream or other surface-water body

Hydraulic gradient – The slope of the water-table surface

Induced infiltration – Water that moves from a stream, river or other surface-water body into an aquifer, due to the pumping of a nearby well

Recharge area – Geographic area where rainfall and snowmelt infiltrate the land surface and provide water to a well

Observation well – A well installed primarily for the purpose of observing water-level drawdown and recovery

Pumping Test – A controlled test, involving the pumping of a test well, for the purposes of evaluating sustainable well yield, water quality and impacts to the environment

Safe Yield – This term was previously used interchangeably with Firm Yield, however, now the term Safe Yield is no longer in use for reservoirs, and is now only used to refer to the yield of the Commonwealth's major river basins.

Test well – A well installed primarily for the purpose of pumping water

Till – A mixture of soils consisting of clay, silt, sand, gravel, cobbles and boulders deposited beneath an advancing glacier or dropped-in-place as the glacier melted away. Also, termed, "hardpan"

Unconfined Aquifer – An aquifer, such as a sand-and-gravel aquifer, that is not covered by a confining layer

Water-level drawdown – The decline in the groundwater level or surface-water level caused by pumping of a nearby well

Water-level recovery – The rise of the groundwater level or surface-water level observed when pumping of a nearby well ceases

Well Yield – The sustainable capacity of a well, measured in gallons per minute

Zone II – The theoretical area of an aquifer that contributes water to a well or well field when pumping at full capacity for 180 days without natural recharge occurring.

Zone III – A secondary recharge area, where groundwater and surface water flow downhill into Zone II. Typically, these are areas underlain by till that shed water into sand-and-gravel aquifers

Executive Summary

Introduction

The Town of Ipswich (Town) provides drinking water to approximately 4,500 homes and businesses throughout the Town. From 2012 to 2016, the total average day demand (ADD) was 1.01 million gallons per day (MGD). The Town utilizes groundwater and surface-water sources in the Parker River Basin, and groundwater sources in the Ipswich River Basin. The Town's current approved daily water-supply capacity is 2.19 MGD. This figure is based on the sum of the approved Safe Yield of the reservoir system and the maximum daily pumping rates approved for each well by the Massachusetts Department of Environmental Protection (DEP). However, this capacity of 2.19 MGD is somewhat deceiving. Operational and water quality issues, and regulatory restrictions could reduce the available capacity to as low as 0.96 MGD during drought conditions. The Water Management Act (WMA) authorizes the Town to withdraw on average a total of 1.18 MGD over the year, 0.98 MGD from the Parker River Basin and 0.2 MGD from the Ipswich River Basin.

In 2016, the Town experienced a significant drought during which the water levels in the reservoirs dropped substantially. By August of that year, the reservoirs were nearly out of water. To meet demands for potable water, the Town had to issue an Emergency Water Supply Declaration and implement very strict water restrictions. In addition, the Town is experiencing modest growth in both residential and commercial sectors. This growth, coupled with the drought of 2016, prompted the Town of Ipswich to retain AECOM to conduct a study of the Town's water system. The purpose of this study was to evaluate current and future drinking water demands, along with current and future water supply. The goals for the study are presented below:

1. Estimate the Town's projected water demands to 2040;
2. Evaluate the capacity of current and potential water-supply sources;
3. Identify the variance between supply and demand; and
4. Recommend new water-supply sources to meet future demand

Ipswich Water Supply Background Information

The Town began providing water to the community in 1894. Since that time, the Town has continued to evolve and has periodically evaluated demands and explored other potential sources of water supply. As part of AECOM's study, it was useful to review the history of water-supply development and the possible sources of municipal water supply the Town has considered over the past 130 years.

The Town of Ipswich first investigated sources of municipal water supply in 1889, primarily as a means of improving public health. Bull Brook Reservoir was constructed in 1923, though its use was discontinued a few years later due to poor water quality. Dow Brook Reservoir was enlarged twice – in 1924 and 1965 – to increase the Town's water supply. Groundwater supplies were connected to the drinking water system from the 1940's through the 1980's. In 1988, Bull Brook and Dow Brook Reservoirs were connected to the newly-constructed Water Treatment Plant (WTP), actions that increased the water supply and dramatically improved water quality. [Ref: J Engel]

Water Demands

AECOM identified existing water demands and estimated projected water demands through the year 2040. Water demand projections were developed using the methodology described in the Commonwealth's Policy for Developing Water Needs Forecasts ("the Policy"), issued in December 2007 and revised in March 2017. The Policy is the standard used by the Commonwealth's Water Resources Commission (WRC) to develop water needs forecasts when public water suppliers and communities seek increased water withdrawals under the WMA. AECOM worked closely with the Town of Ipswich Planning and Water Departments and the Massachusetts Department of Conservation and Recreation (DCR) while developing the existing and projected water demands. These agencies provided AECOM useful historical records and information on development trends. AECOM also coordinated with DCR, which independently conducted a water-needs forecast for Ipswich using the Policy as part of Water Resources Commission activities, to compare and discuss results.

To identify the baseline water demand in Ipswich, AECOM reviewed the Town's Annual Statistical Reports (ASRs) for the years 2012-2016. The baseline average day demand (ADD) for this five-year period was found to be 1.01 MGD.

Future water demands were projected for residential and non-residential uses. In making these projections, we assumed that the Town of Ipswich would maintain the WRC performance standard of 65 residential gallons-per-capita-per-day (RGPCD) in the coming years. The average per capita water demand over the years 2012-2016 was actually 48.4 RGPCD, or approximately 33% less than the WRC performance standard. This lower-than-average RGPCD was due largely to the introduction of monthly billing in 2000, and a seasonal rate structure in 2003 to manage summer demands. The Town's drought management policy and imposed water-use restrictions also contributed to lowering the RGPCD. To account for the uncertainty of future per capita water demand during non-drought conditions, as well as the inherent uncertainties of projecting future growth, AECOM used the WRC performance standard of 65 RGPCD in making demand projections. The projected average- and maximum-day water demands are presented in Table ES-1.

Table ES-1. Projected Average and Maximum Day Demand in 2040

Projected ADD in 2040 (MGD)	Typical MDD/ADD Peaking Factor for Ipswich	Projected MDD in 2040 (MGD)
1.39	3.00	4.17

Notes:

1. Estimated using modified methodology presented in the Commonwealth's Policy for Developing Water Needs Forecasts, as described in this memorandum.

Existing Water Supply

The Town utilizes groundwater and surface-water sources within the Parker River Basin, as well as groundwater sources within the Ipswich River Basin. The surface-water sources include Dow Brook Reservoir and Bull Brook Reservoir. The groundwater sources include the following wells: the Mile Lane, Browns, Fellows Road, Essex Road and Winthrop Wells. Because the two reservoirs operate in series as a reservoir system, the approved daily withdrawal amount is equal to the Safe Yield of the reservoir system. The Safe Yield of the reservoir system, calculated in 1988 to be 0.8 MGD, is documented in the Town's Parker River Basin WMA Permit.

The withdrawal rates authorized under the WMA by DEP dictate how much water DEP allows to be withdrawn from each of the river basins on an annual basis, and individual sources on a daily basis. Therefore, although individual sources may be approved for a specific daily withdrawal volume, the Town must limit the total amount of water it is taking from each individual basin annually. When calculating the current available water-supply capacity, these factors, as well as each source's operational limitations are taken into account. The Town's current available water-supply capacity is restricted to as low as 0.96 MGD during drought conditions and is not sufficiently reliable to meet the current demands. To meet the projected future demand in the year 2040, the Town will need to maintain their existing sources and increase their water supply by approximately 0.43 MGD during drought conditions.

Revised Reservoir Firm Yield

The Ipswich reservoir system includes two sources: the Bull Brook and Dow Brook Reservoirs. These sources are interconnected and provide water to the Town after it is treated at the Ipswich Water Treatment Plant (WTP). The Safe Yield of the reservoir system was calculated in 1988 and estimated to be 0.8 MGD. The Safe Yield was based on the 1 in 20 year drought (a drought that statistically may occur once every twenty years), as determined using another consultants' Reservoir Storage-Yield Computer Simulation Model (RESSIM). This Safe Yield is documented in the WMA permit for the Parker River Basin. Based on the permit, withdrawals for Dow and Bull Brook Reservoirs must not exceed 0.8 MGD as an annual average.

For this study, AECOM recalculated the capacity of the reservoir system based on updated hydrologic and bathymetric data. When researching the latest methods for calculating the Safe Yield and through conversations with DEP, we found that, historically, the terms Safe Yield and Firm Yield had been used interchangeably. The term Safe Yield is no longer in use for reservoirs, and is now only used to refer to the yield of the Commonwealth's major river basins. The term Firm Yield is now used when referring to the capacity or yield of a reservoir or reservoir system. DEP also noted that there was no specific guidance on how to calculate a reservoir's Firm Yield/Safe Yield until the late 1990s/early 2000s. Prior to the late 1990s, consultants and water suppliers had their own approaches for calculating Safe Yield/Firm Yield. In the 2000s, DEP and the US Geological Service (USGS) formalized a methodology for calculating Firm Yield. The latest USGS Firm Yield methodology is described in its report entitled "Refinement and Evaluation of the Massachusetts Firm-Yield Estimator Model Version 2.0".

AECOM used the USGS model to estimate the Firm Yield of the reservoir system. The model predicted that the Dow and Bull Brook reservoir system "fails" (when water levels are such that water can no longer be withdrawn from the reservoirs) first during the drought of 2016. The drought that occurred in 2016 resulted in the lowest Firm Yield of 0.41 MGD, therefore this period is considered to be the worst drought of record in the Town of Ipswich. The drought in the 1960's resulted in the second lowest Firm Yield of 0.45 MGD and the drought in 1997 resulted in the third lowest Firm Yield of 0.47 MGD.

Screening of New Water Supply Sources or Expansion of Existing Sources

AECOM's assessment of existing supply and future demands indicates that additional sources of drinking water are needed to provide Ipswich with sufficient drinking water for the present and future. Additional sources could be realized by adding new sources, expanding existing sources, or a combination of both. At the outset of the project, AECOM and the Town developed a list of seven potential new or expanded sources to be evaluated: After an initial review, an eighth option (increasing raw water storage by adding large storage tanks) was added to the list of options. These eight options are presented below:

1. New Well Field(s)
2. Reservoir Expansion - Raising Existing Dams
3. Reservoir Expansion - Excavating Around Reservoirs/Removing Sediment
4. Reservoir Expansion - Building New Upstream Dams
5. Reservoir Expansion- Building Storage Tanks
6. Desalination
7. Wastewater Reuse
8. Interconnections with Surrounding Communities

The overriding goal of the initial screening step was to identify the three most advantageous options from the list above for further investigation. Each of the eight alternatives was evaluated using the following screening criteria: potential capacity gained, technical feasibility, permit requirements, stakeholder concerns, treatment requirements, additional staffing needs, concept-level costs and schedule for implementation.

During the screening process, we inevitably had to make certain assumptions and judgements where information on each of the screening criteria was incomplete. AECOM worked closely with the Town to select the three most advantages alternatives, shown below:

1. New Lynch Well Site
2. Browns Replacement Well
    a. Browns Replacement Well with Transmission Main to the WTP, or
    b. Browns Replacement Well with a new Greensand Filtration Plant
3. Desalination (brackish groundwater).

We should point out that, during the course of AECOM's water-supply and demand investigation, the Town decided to proceed with testing of the Lynch Well Site for new groundwater supply, under the DEP New Source Approval process. As of January 2019, the Lynch Well Site is awaiting DEP approval. Should DEP approve the Lynch Site, it could provide up to 0.73 MGD of new water-supply capacity.

Three Recommended New Water Supplies or Expansion Alternatives

As stated above, the following three alternatives were selected for more detailed evaluation:

1. New Lynch Well Site
2. Browns Replacement Well
    a. Browns Replacement Well with Transmission Main to the WTP, or
    b. Browns Replacement Well with a new Greensand Filtration Plant
3. Desalination (brackish groundwater).

Alternative 1:

The Town made a concerted effort to identify a new source of groundwater supply in 2016 and 2017. Test wells were drilled at the Browns Well, at Bull Brook Reservoir, near the Mile Lane Well, at Pony Express (Candlewood Drive), at Project Adventure (High School) and at the Lynch Well Site (Linebrook Road). The details of the test-well drilling were reported to the Town in three separate reports:

1. "Replacement Well Investigation, Browns Well", AECOM, March 2016
2. "Test Well Investigation, Bull Brook Reservoir, Mile Lane, & Lynch Property", January 2017
3. "Report On 2017 Test Well Investigation Pony Express and Project Adventure Sites, Ipswich, MA", AECOM, October 2017

Based on these investigations, the Lynch Well Site appeared to be the most favorable of these sites in terms of capacity and water quality.

A 15-day prolonged pumping test conducted at the Lynch Site in August 2018 indicates that a well field of four wells could produce up to 510 gpm or 0.73 MGD. Water-quality testing conducted during the pumping test indicates that the water meets primary and secondary Maximum Contaminant Levels (MCLs and SMCLs) established by the US Environmental Protection Agency (EPA) and enforced by the Massachusetts DEP. Low levels of bacteria and per- and poly-fluorinated alkyl acids (PFAAs) were found along with elevated levels of nitrate, chloride, and sodium.

Alternative 1 Next Steps:

- Obtain approvals from the appropriate state regulatory agencies, i.e., DEP and MEPA;
- Investigate the source(s) of bacteria, and eliminate pathways for their introduction into the groundwater;
- Investigate the sources of nitrate, sodium, chloride and PFAAs, and develop a plan to reduce their levels in groundwater;
- Obtain local approvals, such as an Order of Conditions from the Conservation Commission;

- Identify an adequate, alternative source of water for irrigation to maintain farming operations; and
- Design wells and pumping facilities.

Alternatives 2a and 2b:

The use of Browns well is included as part of Alternatives 2a and 2b. Browns well and its associated pump station have reached their useful service life. The well pumps water directly into the distribution system and has historically been a productive well for the Town, but manganese levels have been increasing over the years. In a letter report dated March 31, 2016, AECOM recommended that the well and pump station be replaced with a gravel-packed replacement well to be constructed 15 feet from the existing Browns well. Pumping tests indicated that the replacement well could be capable of producing up to 400 gpm. In addition, the Browns well water will require treatment for iron and manganese.

Alternatives 2a and 2b would both include the replacement of Browns well. However, Alternative 2a would entail constructing a transmission main from the well to the existing WTP for treatment. Alternative 2b would involve constructing a new greensand filtration plant to treat the water for iron and manganese, followed by pumping directly into the distribution system.

The initial steps in the development process for Alternatives 2a and 2b are summarized below:

Alternative 2a Next Steps:

- Prepare a layout of the transmission main from Browns well to the WTP.
- Begin permitting process for the replacement well.
- Conduct survey and borings along the transmission main route in preparation for design.
- Conduct jar testing to assess adjustments to chemical addition at the WTP.
- Evaluate the existing WTP.

Alternative 2b Next Steps:

- Begin permitting process for the replacement well.
- Conduct survey and borings at Lot 009 in preparation for design.

Alternative 3: Desalination

Alternative 3 would involve constructing a new desalination water treatment plant to treat brackish groundwater. The plant would likely use reverse osmosis technology to remove salt and minerals from brackish groundwater to obtain fresh water. The desalination process produces high-salinity brine as a byproduct, which would need to be discharged to the ocean. Brackish groundwater would be pumped to the desalination plant, which could be located on Town property near the existing wastewater treatment plant (WWTP). Several positive circumstances made this alternative worthy of investigation:

- The Town owns coastal land at the WWTP, which could be a source of brackish groundwater;

- The WWTP has an existing outfall that discharges to the Greenwood Creek, which is a tidal creek. Any brine that is created through the treatment process could be mixed with the WWTP effluent and discharged through the same outfall.

- The proposed site is located close to the Town Hill water storage tank, adjacent to the WWTP site on Town owned property. Desalinated water would be introduced to the distribution system at the tank.

Before any further consideration of desalination, the Town would need to identify if there is a sufficient supply of brackish groundwater at the WWTP site.

Some of the next steps for further evaluating this option are summarized below:

- Drill test wells to identify possible brackish groundwater sources;
- Conduct geotechnical borings and survey at the site;
- Consider the optimum capacity of the plant.

Based on the evaluation of the three alternatives, the Town decided to move forward with the Lynch Well alternative. AECOM also recommends that the Town proceed with replacing Browns Well and constructing a transmission main extending from the well to the WTP. Estimated costs for each alternative are presented in the table below. This Browns Well option is the least expensive of the remaining alternatives recommended for further evaluation and will increase the capacity by 0.28 MGD. Increasing the Browns well capacity to 400 gpm (0.28 MGD) and DEP approval of the Lynch Well Site (up to 0.73 MGD), will provide the additional water supply needed by the Town. The Browns Well has been a reliable water source for the Town and, with treatment for iron and manganese, it can continue to provide water. We recommend that a bench-scale jar-testing study be conducted to evaluate the impacts Browns Well water on the WTP process. Available water-quality data indicates that the quality of the surface water from Dow Brook and Bull Brook Reservoirs is similar to the quality of Browns Well. We also recommended that the Town move forward with a test-well investigation to further evaluate the desalination option. This investigation will provide information for the Town to plan for future demands and for redundancy.

Table ES-2. Recommended Alternatives Concept Level Opinion of Costs

Alternative No.	**Concept Level Opinion of Costs**	**Capacity Increase (MGD)**
Alternative No. 1: Lynch Well Site	$2,960,000	0.73
Alternative No. 2a: Browns Replacement Well with Transmission Main to WTP	$1,600,000	0.28
Alternative No. 2b: Browns Replacement Well with Greensand Filtration Plant	$5,125,000	0.28
Alternative No. 3: Desalination	$25,000,000	3.0

1 Introduction

The Town of Ipswich (Town) provides drinking water to approximately 4,500 homes and businesses throughout the Town. From 2012 to 2016, the total average day demand (ADD) was 1.01 million gallons per day (MGD). The Town utilizes groundwater and surface-water sources in the Parker River Basin, and groundwater sources in the Ipswich River Basin. The Town's current approved daily water-supply capacity is 2.19 MGD. This figure is based on the sum of the Safe Yield of the reservoir system and the maximum daily pumping rates approved for each well by the Massachusetts Department of Environmental Protection (DEP). However, this capacity of 2.19 MGD is somewhat deceiving. Operational and water quality issues, and regulatory restrictions reduce the available capacity to 0.96 MGD during drought conditions. The Water Management Act (WMA) authorizes the Town to withdraw on average a total of 1.18 MGD over the year, 0.98 MGD from the Parker River Basin and 0.2 MGD from the Ipswich River Basin.

The reservoir system in Ipswich includes the Dow Brook and Bull Brook reservoirs. The reservoir system is located in the Parker River Basin and provides about half of the potable water supply to the Town. The reservoirs operate in series, with water flowing from the Bull Brook Reservoir to the Dow Brook Reservoir. Water is then pumped from the Dow Brook Reservoir to the Water Treatment Plant (WTP). Historical observations and AECOM's work have confirmed that these reservoirs operate on an annual cycle, including: 1) overtopping the dams in the late fall, winter, and early spring months and 2) reduction in reservoir levels in the summer and early fall. The water that is overtopping the dams is lost to the Town for use as drinking water supply. These observations indicate that the reservoir volume is insufficient to store the water contributed from their watershed areas. The reservoirs are also insufficient to maintain adequate capacity of potable water for the Town. If additional storage volume was available, the water that is currently overtopping the dams could be stored and would create a buffer during high demand and/or low rainfall periods. In addition, because of this low storage volume, the reservoirs are more dependent on the timing of rainfall. If the late spring and summer months are dry, the reservoirs receive very minimal inflow and the water levels typically drop quickly.

In 2016, the Town experienced a significant drought, during which the water levels in the reservoirs dropped substantially. To meet demands for potable water, the Town had to implement severe water use restrictions, and institute an Emergency Water Supply Declaration. In addition, the Town is experiencing modest growth in both residential and commercial sectors. This growth, coupled with the drought of 2016, prompted the Town to retain AECOM to conduct a study of the Town's water system. The purpose of this study is to evaluate current and future drinking water demands, along with current and future water supply. The overall goals for the study are presented below:

1. Estimate the Town's projected water demands to 2040;
2. Evaluate the capacity of current and potential water-supply sources;
3. Identify the variance between supply and demand; and
4. Recommend new water supply sources to meet future demand.

1.1 Ipswich Water Supply Background Information

This section provides a more complete rationale for the study, along with a history of water supply development. The Town began providing water to the community in 1894. Since that time, the Town has continued to evolve and has periodically evaluated demands and explored other potential sources.

<u>Rationale for Water Supply and Demand Study</u>

Several concerns about the Town's water supply have brought into sharp focus the need for the Town of Ipswich to assess new sources of water supply. These concerns, summarized below, involve a wide range of water-supply considerations, including capacity, water quality, operations, regulation and long-term planning.

1. The recognition that the capacity of the Town's reservoir system, namely the Dow and Bull Brook Reservoirs, appears less than the Safe Yield of 0.8 MGD, established during the 1980s. The reservoirs are especially inadequate during dry summers.
2. Restricted use of the wells in the Ipswich River Basin, namely, the Fellows Road, Essex Road and Winthrop Wells. These restrictions, imposed by DEP under the Town's WMA Registration, limit pumping to no more than 0.2 MGD on average over the year. The restrictions are aimed at maintaining acceptable flows in the Ipswich River during the summer months. The approved daily pumping capacity of the five Ipswich River Basin wells is 1.39 MGD in aggregate. Therefore, the Town is only allowed to use 14% of the capacity of the wells in the Ipswich River Basin.
3. Escalating levels of manganese in the Browns Well (located in the Parker River Basin). To manage this problem, the Town now limits pumping to no more than about 0.2 MGD, less than half the permitted capacity of 0.49 MGD.
4. Elevated levels of iron and/or manganese in the Fellows Road Well and Winthrop Wells (all located in the Ipswich River Basin). Two of the three Winthrop Wells are inactive due to these water-quality issues. Absent the WMA restrictions, the Town might consider construction of a water-treatment plant to remove iron and manganese, and make full use of the 1.39-mgd approved daily pumping capacity.
5. The need to plan for growth in water demand as the population and local economy expand in the coming decades.
6. The need for operational flexibility and drought resiliency in the water system.

Fortunately, the Town has been able to manage demand through a set of local controls. It is interesting to note that average-day demand peaked in 1995 at 1.35 MGD, when the population was 12,869. Demand continued to be similarly high through the year 2000. Between 2012 and 2017, the average-day demand declined dramatically, to a range of 0.93 to 1.02 MGD, despite a 4% increase in population (13,390 year-round residents in 2016).

The principal reasons for the reduction in demand appear to be the following:

a. In 2003, the Town implemented a summertime water-rate schedule for residential customers. These rates apply from May 1 to September 30 of each year, and are 1.5 times the base rate. For 2018, the summer rate was $12.99 per hundred cubic feet, nearly four times the winter rate.
b. A Water-Use Restriction Bylaw was adopted by the Town in 2017. This bylaw grants greater authority to the Water Commissioners, or their designee, to impose restrictions to reduce consumption "at any time that conditions warrant".
c. Monthly reading of water meters and monthly billing of all customers began in the year 2000. This allows the Town to closely monitor and manage consumption.
d. Greater public awareness and public participation in water-conservation efforts.

Before we report the details of AECOM's 2018 Water Supply and Demand Study, it is useful to review the history of water-supply development and the possible sources of municipal water supply the Town has considered over the past 130 years.

<u>History of Water-Supply Development</u>

The Town of Ipswich first investigated sources of municipal water supply in 1889, primarily as a means of improving public health. At that time, water-borne diseases were prevalent in the community due to a combination of unsanitary practices, including: privies for human waste disposal, farm and draft animals on residential lots, and shallow private drinking-water wells. The Town considered surface-water supply from Hoods Pond, the Ipswich River and the Egypt River, and groundwater supply from wells along the Ipswich River. None of these supplies was developed. [Ref: J Engel, CDM, 1961]

Two large fires that occurred in early 1894, along with continued public-health concerns, prompted the Town to call a Special Town Meeting to authorize construction of the Dow Brook Reservoir, with future plans for a reservoir at Bull Brook. Dow Brook Reservoir, along with 10.9-miles of water-distribution piping and an open 1.6-million gallon storage reservoir on Town Hill, were constructed and in service by the end of 1894. [Ref: J Engel] This original supply of about 400,000 gallons per day served a population of about 4,500.[CDM, 1961]

Bull Brook Reservoir was constructed in 1923, though its use was discontinued a few years later due to poor water quality. Dow Brook Reservoir was enlarged twice – in 1924 and 1965 – to increase the Town's water supply. In 1988, Bull Brook and Dow Brook Reservoirs were connected to the newly-constructed WTP, actions that increased the water supply and dramatically improved water quality. [Ref: J Engel]

In the decades following World War II, the proliferation of modern plumbing, modern appliances, such as washing machines and dishwashers, and changing habits, such as lawn irrigation, increased the Town's demand for water. To illustrate this point, the demand increased from 0.55 MGD in 1950 to nearly 1.0 MGD by the mid-1960s [CDM, 1967]. To meet these demands, between 1942 and 1981, the Town undertook numerous groundwater investigations, resulting in the construction of seven well supplies.

Table 1-1 summarizes the development history of the Town's existing water supplies.

Table 1-1. Historical Summary of Existing Water Supplies[1]

Water Supply	Year Operational	Brief History and Status
Dow Brook Reservoir	1894	Expanded in 1923 and 1965, connected to Water Treatment Plant in 1988
Bull Brook Reservoir	1923	Discontinued in 1920s due to poor water quality, connected to Dow Brook Reservoir and Water Treatment Plant in 1988
Mile Lane Well	1942	Currently operational
Browns Well	1942/1954	Original well abandoned due to pumping of sand; replaced in 1954 with currently operating Browns Well
Winthrop #1	1961	Inactive
Winthrop #2	1962	Currently Operational
Winthrop #3	1976	Abandoned
Essex Road Well	1977	Currently operational
Fellows Road Well	1981	Currently operational

Note 1. Table 1. [Ref: J Engel]

<u>Historical Groundwater-Supply Exploration</u>

As stated above, the Town has been investigating prospects for new groundwater-supply since the late 19th Century. Since that time, test wells have been driven at over 130 locations throughout Town. The following summarizes the groundwater exploration efforts documented in Town records made available to AECOM:

- 1893 Test-Well Investigation, 18 test-wells drilled in the downtown area, along County Road and Topsfield Road near the Ipswich River;
- 1941 Test-Well Investigation, 18 test-wells driven along Mile Lane, Linebrook Road, and High Street, resulting in the construction of the Mile Lane Well and the original Browns Well;

- 1954 Test-Well Investigation, 52 test-wells driven along the Ipswich and Miles Rivers and in Willowdale State Forest, which eventually led to the development of Winthrop Well #3;
- 1958 Test-Well Investigation, 21 test-wells driven in previously explored areas, eventually resulting in the development of the two, original Winthrop Wells;
- 1967 Test-Well Investigation, additional test wells at Hood Pond;
- 1990's Bedrock Well Investigation, no test wells were drilled;
- 2006 Test-Well Investigation, 4 test wells near Maria Drive;
- 2016-2017 Test-Well Investigations, 26 test-wells driven at the Browns Well, Bull Brook Reservoir, Mile Lane, the Lynch Site, Project Adventure (adjacent to the High School) and Pony Express.

<u>Other Sources of Supply Considered</u>

In the 1960s and 1970s, the Town considered other sources of supply, including:

- Diversion of the Ipswich River during springtime; construction of impoundments on Kimball Brook, Corseys' Brook, or the Pine Swamp area. In the late 1970s, the Town's consulting engineers concluded that this was the Town's only long-range solution for water supply.
- A regional system using water diverted from either the Merrimack or Concord Rivers;
- Purchase of water from outside the Town;
- A regional reservoir; and
- Desalination (energy-intensive distillation rather than current membrane technology).

In the mid-1990s, the Town investigated:

- Expansion of Bull Brook and Dow Reservoirs

And, in 2003, the Town considered:

- The feasibility of diverting wastewater effluent to water-supply recharge areas.

Obviously, none of these solutions was implemented. While we do not know the specific reasons each of these ideas was rejected, we suspect it was due to a number of factors, including cost, technical feasibility, permitting, public approval, legal/legislative matters, or other reasons.

<u>The Challenge of Developing New Sources of Supply</u>

It is interesting to note that in the late 1970s, the Town's consulting engineers concluded that the Town's only long-range solution for water supply was to divert water from the Ipswich River. In today's regulatory environment, a river diversion would be difficult to permit. Furthermore, to our knowledge, no new surface-water supply has been permitted in New England in the last 40 years.

Past consulting engineers ruled out future groundwater supplies because it appeared that sand and gravel deposits were limited. This is understandable, as the Town had explored many areas for well supplies with limited success. However, recent exploration has been successful. In AECOM's experience, the challenge of identifying groundwater supply in Ipswich stems from the following both natural and man-made circumstances:

- The aquifer that supplies both the Browns and Mile Lane Wells (and probably the Lynch Well Site) is thin, discontinuous and buried beneath a widespread layer of clay. For this reason, this aquifer has proven to be elusive in identifying and developing. Further, the widespread nature of the clay layer may limit aquifer recharge. However, once the sources were found, they have proven to be good sources of supply.

- Outside the Ipswich River basin, the watersheds are generally small, which limits well yield.
- Wetlands, which can cause elevated levels of iron and/or manganese in well water, are widespread.
- To protect long-term water quality and comply with DEP regulations, municipal wells must be situated on large parcels of land owned by the Town, which in Ipswich are limited in number. In addition, well supplies must be reasonably remote from human activity.
- Like many communities in eastern Massachusetts, the Town has grown up around the water supplies. Therefore, the development of land for human activities has crowded out land available for water supply.
- The shallow aquifer above the clay is generally too thin and fine-grained to support a municipal supply. Farm ponds in the shallow aquifer can supply water for irrigation purposes, but it is doubtful that a supply of municipal-scale could be sustained every day, year-after-year.
- New sources of groundwater in the Ipswich River Basin can be ruled out because the Town's WMA registered withdrawal volume restricts pumping from the Town's existing wells in the Ipswich River Basin to 0.2 MGD.

2 Water Demands

The first step in AECOM's evaluation was to identify the existing and projected water demands for the Town of Ipswich for the year 2040. Water-demand projections were developed using the methodology described in the Commonwealth's Policy for Developing Water Needs Forecasts ("the Policy"), issued in December 2007 and revised in March 2017. Departures from this methodology are identified, as needed, throughout this summary. The Policy is the standard used by the Commonwealth's Water Resources Commission (WRC) to develop water needs forecasts when public water suppliers and communities seek increased water withdrawals under the WMA. AECOM worked closely with the Town of Ipswich Planning and Water Departments and the Massachusetts DCR to develop the projected water demands. These agencies provided AECOM useful historical records and information on development trends. AECOM also coordinated with DCR, which independently conducted a water-needs forecast for Ipswich using the Policy as part of WRC's normal activities, to compare and discuss results.

Future water demand was projected for residential and non-residential uses as described below.

2.1 Existing Water Demand

To identify the baseline water demand in Ipswich, AECOM used the Town's Annual Statistical Reports (ASRs) for years 2012-2016. The baseline average day demand (ADD) for this five-year period was 1.01 MGD. The average day peaking factor, or ratio of maximum day demand (MDD) to ADD, is 3.00 (see Table 2-1). The ADD and MDD account for all raw water, including surface water entering the Town's WTP and groundwater from the Town's active wells.

Approximately 98 percent of the Town's population is served by the municipal water system. Table 2-2 identifies the estimated current population served by the Town. There are approximately 200 seasonal homes in Ipswich. It is assumed that these homes are occupied for three months of the year. The annualized seasonal population is estimated to be 119 people. Additional baseline water demand information for the Town of Ipswich based on the spreadsheet template provided as part of the Policy is shown in Table 2-3. Table 2-3 is populated using an average of data obtained from the Town's ASRs for years 2012-2016.

Table 2-1. Baseline Water Demand

Year	Total Pumped (mgy)[1]	ADD (mgd)[2]	MDD (mgd)[3]	MDD/ADD Peaking Factor
2012	357.67	0.98	2.96	3.02
2013	362.42	0.99	3.38	3.40
2014	377.77	1.03	2.95	2.85
2015	383.59	1.05	3.10	2.95
2016	368.87	1.01	2.83	2.80
Avg.[4]	370.07	1.01	3.04	3.00

Notes:

1. Total raw water pumped data for 2012 through 2016 from DEP Annual Statistical Report.
2. ADD: Average day demand, rounded to the nearest 0.01 mgd.
3. MDD: Maximum Daily Raw Water Pumping reported in DEP Annual Statistical Report.
4. Reflects average total pumped, average ADD, and average MDD.

Table 2-2. Baseline Population

	Current Population				
(A)	(B)	(C)	(D)	(E)	(F)
Community	Town Pop[1]	% Served Pop[2]	Out-of-Town Pop[2]	Annualized Additional Seasonal Pop[3]	Base Service Pop
Ipswich	13,390	98.0%	0	119	13,241

Notes:

1. Source: Population data from the Town of Ipswich's DEP ASR for the year 2016.
2. Source: Town of Ipswich.
3. Assumes: (a) 200 seasonal homes (Source: Town of Ipswich), (b) average home occupancy of 2.38 (Source: 2010 Census), and (c) homes are occupied for three months of the year.

Table 2-3. Baseline Water Use

Comment: Percentages add up to 100.5%

		Residential		Non-Residential		Treatment Loss[2]		UAW[2]	
(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)	(P)
Base System ADD (mgd)	Res ADD (mgd)	Res % of Base ADD	Res GPCD[1]	Non-Res ADD (mgd)	Non-Res % of Base ADD	Treatment Plant Processing Loss (mgd)	% Treatment Plant Processing Loss	UAW ADD (mgd)	UAW % of Base ADD
1.01	0.64	63.2%	48.4	0.23	22.6%	0.0545	5.4%	0.09	9.3%

Notes:

1. RGPCD: Residential gallons per capita per day.
2. Water lost during treatment of surface water.
3. UAW: Unaccounted for water.
4. Source: Average of data from the Town of Ipswich's DEP ASRs for years 2012-2016.

2.2 Projected Water Demand

Future water demands were projected for residential and non-residential uses. In making these projections, we assumed that the Town of Ipswich would maintain the WRC performance standard of 65 residential gallons-per-capita-per-day (RGPCD) in the coming years. The average per capita water demand over the years 2012-2016 was actually 48.4 RGPCD, or approximately 33% less than the WRC performance standard. This lower-than-average RGPCD was due largely to the introduction of monthly billing in 2000, and a seasonal rate structure in 2003 to manage summer demands. The Town's drought management policy and imposed water restrictions also contributed to lowering the RGPCD. To account for the uncertainty of future per capita water demand during non-drought conditions, as well as the inherent uncertainties of projecting future growth, AECOM used the WRC performance standard of 65 RGPCD in making demand projections. For comparison purposes, ADD and MDD were also calculated under a lower residential water demand scenario of 48.4 RGPCD in Section 2.2.4 (Total Projected 2040 Water Demand for Ipswich).

In making these projections we also assumed that the MA WRC performance standard of 10% unaccounted for water (UAW) would be applied through the year 2040 and there would be no future inter-municipal demand.

2.2.1 Residential Demand

The population projections used to forecast future residential water demand for Ipswich in the year 2040 were based on projections prepared by the Massachusetts Department of Transportation (MassDOT) in 2015.[1] The MassDOT projections were modified[2] to reflect the population data available in the Town's current (2016) ASR. It is estimated the Town's population will increase from 13,390 year-round residents in 2016[3] to 14,128 year-round residents in 2040. This represents a population increase of approximately 5.5% (738 persons). It was assumed 98% of the Town's population would be served by Ipswich water in 2040 based on information provided by the Town. It was assumed that the seasonal population would remain constant.

The future residential demand was estimated by applying the MA WRC performance standard of 65 GPCD to the base service population plus the projected increase of 738 persons. This resulted in a projected residential demand of approximately 0.91 MGD compared to the existing demand of 0.64 MGD.

2.2.2 Non-Residential Demand

Future non-residential water demands for Ipswich were estimated using available employment projections per the Policy's methodology. Employment projections prepared by MassDOT in 2015 were used.[1] These projections show little change in the number of people employed in the Town of Ipswich between 2016 and 2040 (5,326 and 5,351 respectively). Using the Policy's methodology, the 2040 non-residential ADD for 2040 is approximately 0.23 MGD, which is equal to the current non-residential ADD (see Table 2-4).

2.2.3 Specific Projects Resulting in Additional Demand

The Town of Ipswich provided information about several future development projects that are in various stages of planning and approval that were assumed not to be accounted for in the population and employment projections used for this analysis. Planned and proposed projects are included in Table 2-5. The additional demand for these projects was calculated based on the number of planned residential units and the anticipated water demand for a future brewery and marijuana growing facility. At the time of the preparation of this future water demand, no specific future zoning changes were being considered by the Town.

Based on these assumptions, the anticipated additional demand associated with the three residential and two non-residential projects presented in Table 2-5 is 0.050 MGD.

2.2.4 Total Projected 2040 Water Demand for Ipswich

The projected additional raw water demand for the Town of Ipswich in 2040 was determined using the approach described above and the modified Policy spreadsheet template. The projected raw water ADD for the Town of Ipswich in 2040 is approximately 1.39 MGD, which is the sum of 0.91 MGD (residential), 0.23 MGD (non-residential), 0.05 MGD (specific projects), 0.13 MGD (UAW) and 0.07 MGD (treatment loss). The projected ADD is 0.38 MGD greater than the current base system ADD of 1.01 MGD, and in excess of the Town's current approved WMA withdrawal volume of 1.18 MGD. DEP plans to renew WMA Permits for the Parker River Basin in 2023. At this time, Ipswich will have an opportunity to request additional permit volume. The projected MDD is 4.17 MGD (see Tables 2-6 and 2-7).

If residential water demand continues at a rate equal to the average RGPCD of the last five years (48.4 RGPCD), the projected ADD and MDD in 2040 would be 1.11 and 3.32 MGD, respectively.

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[1] Provided by Michele Drury, Massachusetts Department of Conservation and Recreation, via email 12/21/17.
[2] An average annual growth rate of 0.224% was derived from the population change from 2020-2040 as determined by the MassDOT projections. Future population was estimated based on an annual growth rate of 0.224% from the base population of 13,390 in 2016 to 2040.
[3] Population data from the Town of Ipswich's MassDEP ASR for the year 2016.

Table 2-4. Projected Non-Residential Water Use

Community	Current Non-Res ADD (mgd)	Current Employ-ment[1]	Current Non-Res GPCD	2020 Employ-ment[2]	2020 Non-Res ADD (mgd)	2025 Employ-ment[2]	2025 Non-Res ADD (mgd)[3]	2030 Employ-ment[2]	2030 Non-Res ADD (mgd)	2035 Employ-ment[2]	2035 Non-Res ADD (mgd)	2040 Employ-ment[2]	2040 Non-Res ADD (mgd)
Ipswich	0.23	5,326	42.97	5,320	0.23	5,308	0.23	5,296	0.23	5,324	0.23	5,351	0.23

Notes:
1. Source: Average of 2010 and 2020 population from employment projections prepared by MassDOT in 2015.
2. Source: Based on employment projections prepared by MassDOT in 2015.

Table 2-5. Specific Projects Resulting in Additional Demand

Planned and Proposed Development	Type	Number	Units	Water Demand (gallons/day)	Water Demand (mgd)
Residential[1]					
40B Development Project on Essex Road[2]	Residential	194	Units	30,012	0.030
40B Development Project on Town Farm/ Locust Road[3]	Residential	32	16 Duplexes	4,950	0.005
Development Project on Linebrook Road[4]	Residential	40	Units	6,188	0.006
Total Residential Demand					**0.041**
Non-Residential[5,6]					
Marijuana Growing Facility	Agricultural/Commercial			6,249	*0.006*
True North Ales[7]	Light Industrial			2,571	*0.003*
Total Non-Residential Demand					**0.009**
TOTAL					**0.050**

Notes:

1. Assumes Water Resources Commission's (WRC's) performance standard of 65 residential gallons per capita per day (RGPCD) and an average household size of 2.38 based on 2010 Census data for average household size in Ipswich. Number of units in each project is an estimate provided by Ipswich Planning Department.
2. Assumes 194 units. This development has not been approved by the State as of January 2018. The development may ultimately include fewer units. It is assumed that this development will be completed by 2035.
3. Assumes 16 duplexes. It is anticipated that this development project will be completed by 2025.
4. Assumes 40 units. It is anticipated that this project will be completed by 2025.
5. Estimated projected future demand for growing facility and True North Ales provided by Ipswich Water & Wastewater Department.
6. Assumes that non-residential development projects will be completed by 2020.
7. Assumes that the brewery will use a maximum of 17,000 gallons per week, 7 days per week.
8. The Turner Hill Development (100 units constructed, 30 additional units planned) is not included in the table above. This development is already underway and it is assumed that the population increase associated with this development is already captured in the population projections.

Table 2-6. Water Needs Forecasts to 2040

Year	POPULATION						RESIDENTIAL		NON-RES	UAW		Treatment Loss	
	(Q)	(R)	(S)	(T)	(U)	(V)	(W)	(X)	(Y)	(Z)	(AA)	(AB)	(AC)
	Future Pop[1]	Future % Service Pop[2]	Future Out-of-Town Pop[3]	Future Annualized Add'l Seas Pop[3]	Future Service Pop	Pop Change, Present - Future	Future Res Cons. Rate (GPCD)[4]	Future Res ADD (mgd)	Future Non-Res ADD (mgd)[5]	Future UAW ADD (mgd)[6]	Future Significant Change ADD (mgd)[7]	Future Treatment Plant Processing Loss (mgd)[8]	Future Total ADD (mgd)[9]
2020	13,510	98%	0	119	13,359	368	65	0.87	0.2286	0.12	0.0088	0.0697	1.30
2025	13,662	98%	0	119	13,508	149	65	0.88	0.2281	0.12	0.0200	0.0709	1.32
2030	13,816	98%	0	119	13,658	150	65	0.89	0.2276	0.12	0.0500	0.0732	1.36
2035	13,971	98%	0	119	13,810	152	65	0.90	0.2287	0.13	0.0500	0.0739	1.38
2040	14,128	98%	0	119	13,964	154	65	0.91	0.2299	0.13	0.0500	0.0746	1.39

Notes:

1. Estimated based on current population for the Town of Ipswich from the MassDEP 2016 ASR and the annual growth rate (0.224%) of MassDOT population projections prepared in 2015.
2. Assumes 98% of population is served by Town of Ipswich.
3. Assumes: (a) 200 seasonal homes (Source: Town of Ipswich), (b) average home occupancy of 2.38 (Source: 2010 Census), and (c) homes are occupied for three months of the year.
4. Assumes Water Resources Commission's (WRC's) performance standard of 65 residential gallons per capita per day (RGPCD) for existing and projected population.
5. Estimated based on MassDOT employment projections prepared in 2015.
6. Estimated using WRC's performance standard of 10% unaccounted for water (UAW) loss.
7. Estimated based on future planned developments and additional demand identified by the Town.
8. Water lost during treatment of surface water.
9. Accounts for all projected demand increases including: residential, non-residential, water sold, future significant change from specific developments, and increase in surface water lost during treatment plant processing.

Table 2-7. Projected Water Maximum Day Demand in 2040

Per Capita Demand (GPCD)	Projected ADD in 2040 (mgd)	MDD/ADD Peaking Factor	Projected MDD in 2040 (mgd)
48.4	1.11	3.00	3.32
65	1.39	3.00	4.17

Notes:

1. Estimated using modified methodology presented in the Commonwealth's Policy for Developing Water Needs Forecasts, as described in this memorandum.

3 Existing Water Supply

As mentioned above, the Town of Ipswich provides potable water to approximately 4,500 homes and businesses throughout the Town. In Section 2 of this report, the baseline water demand in Ipswich was calculated using the raw-water production data from the Town's ASR reports for the years 2012-2016. The baseline average day demand (ADD) for this five year period was 1.01 MGD, and the maximum day demand (MDD) was 3.04 MGD. The ADD and MDD account for all raw water, including surface water treated at the Town's WTP and the groundwater from the Town's active wells.

The Town utilizes groundwater and surface water sources within the Parker River Basin, as well as groundwater sources within the Ipswich River Basin. Based on the five years of ASR data, on average, the groundwater makes up 45% of the source water and surface water makes up the remaining 55%. The amount of water the Town can withdraw from the two river basins is set by the DEP under the Town's WMA Permits/Registrations. The Town is authorized to withdraw an average of 0.98 MGD from the Parker River Basin and 0.2 MGD from the Ipswich River Basin over the year. It is noteworthy that the Town's water supply sources that DEP identifies as being includes in the Parker River basin for regulatory purposes under the WMA, are physically located in the Rowley River Basin.

Table 3-1 summarizes the Town's water supply sources by river basin. For each source, the table presents the DEP authorized maximum daily withdrawal rates in MGD. The two reservoirs operate in series as a reservoir system, so the maximum daily withdrawal rate is equal to the Safe Yield of the reservoir system. The Safe Yield of the reservoir system was calculated in 1988 to be 0.8 MGD, which is documented in the Parker River WMA permit. The approved maximum daily withdrawal rates for the wells are equal to the maximum pumping rates approved by DEP. The sum of the maximum authorized daily withdrawal rates is 2.19 MGD.

Table 3-1 also shows the total annual average withdrawal rates authorized under the WMA for the Town's sources in each basin. As stated above, for the Parker River basin, the annual average authorized rate is 0.98 MGD, and for the Ipswich River basin, it is 0.2 MGD. The sum of these two rates is 1.18 MGD.

In the next column on Table 3-1, we present the average daily withdrawal rates for the years 2012 to 2016. In all cases, the actual withdrawal rates from each source were lower than the approved maximum daily rates. The sum of the actual average daily withdrawal rates for 2012 to 2016 is equal to 1.01 MGD.

The last column (on the right) of Table 3-1 shows the current available withdrawal rates, or capacity, for each source. The "available" capacity is a somewhat complicated concept, as a number of factors are involved. In the case of the reservoir system, the Town has long questioned the validity of the Safe Yield. Accordingly, we recalculated the Safe Yield. The 0.8 MGD Safe Yield was replaced by a Firm Yield of 0.41 MGD. (Section 3.1 of this report defines the terms Safe Yield and Firm Yield.) The available capacity of the Browns Well is estimated to be 0.2 MGD. The Town must restrict the use of Browns Well to 0.2 MGD to manage high levels of manganese. Finally, two of the five wells in the Ipswich River basin are inactive. The three remaining wells are limited by the Town's WMA Registration to an annual average of 0.2 MGD.

In summary, the total approved maximum daily pumping rate for the Town's sources is 2.19 MGD. Based on these values, the Town would appear to have sufficient water supply to meet the ADD of 1.01 MGD. However, the withdrawal capacity is restricted to as low as 0.96 MGD during drought conditions due to limited capacity in the reservoir system, indicating a potential supply deficit of 0.05 MGD with all supplies operating. The deficit increases if a supply becomes unavailable due to operational or water quality complications. During the drought of 2016, the Town found that it had to exceed its WMA authorization in the Ipswich River basin (with permission from DEP) and take other measures to meet demand. During wetter years, the Town has more water available. However, the Town has no redundancy or a factor of safety in the event of a source disruption due to a pump failure or source contamination.

Table 3-1 Summary of Existing Water-Supply Sources

River Basin	Water Supply Source	Authorized Maximum Daily Withdrawal Rate (MGD)	Total Authorized Annual Average Withdrawal (MGD)	Average Daily Pumping Rates (MGD) (2012-2016)	Current Restricted Withdrawal Rate (MGD)
Parker River	Dow Brook Reservoir	2.50 (max. pumping rate)	0.98[2]	0.56	0.41[7]
	Bull Brook Reservoir	0.8 (Safe Yield)[1]			
	Mile Lane Well	0.15		0.07	0.15
	Browns Well	0.49		0.12[3]	0.2
Parker River Basin Subtotal		**1.44**	**0.98**	**0.75**	**0.76**
Ipswich River	Fellows Road Well	0.31	0.2[4]	0.12	Combined total withdrawal authorized from these wells 0.2 MGD
	Essex Road Well	0.21		0.09	
	Winthrop Well 2	0.23		0.05	
Ipswich River Basin Subtotal		**.75**	**0.2**	**0.26[5][6]**	**0.20**
Total		**2.19**	**1.18**	**1.01**	**0.96**

Notes:

1. DEP accepted the Safe Yield of 0.8 MGD based on the 1/20 year drought, as determined using Camp, Dresser & McKee's Reservoir Storage-Yield Computer Simulation Model (RESSIM). Withdrawals for Dow and Bull Brook Reservoirs must not exceed 0.8 MGD per day as an annual average. This will be discussed in further detail below.
2. The WMA authorization limits the water use from the Parker River basin to an Annual Average Volume Per Day of 0.98 MGD. It should be noted that because the authorization is in terms of Average Annual Volume per Day, the actual daily withdrawal rate can vary as long as the total volume per year does not exceed 0.98 MGD x 365 days= 357.7 MG. On average between 2012 and 2016, the Town was below the WMA limit for the Parker Basin because the water was not available in the reservoirs.
3. The actual pumping rates are below the available pumping rates due to high manganese concentrations in the source water.
4. The WMA authorization limits the water use from the Ipswich River basin to an Average Volume Per Day of 0.2 MGD. It should be noted that because the authorization is in terms of Average Annual Volume per Day, the actual daily withdrawal rate can vary as long as the total volume per year does not exceed 0.2 MGD x 365 days = 73 MG.
5. In 2016, the Town exceeded its WMA authorization in the Ipswich River Basin, with permission from DEP.
6. The average daily pumping rate also reflects the Town's use of the 100,000 GPD buffer authorized under the WMA. It does not indicate a violation of the existing authorization.
7. The yield for the reservoir system was recalculated for this study and is now presented in terms of a Firm Yield of 0.41 MGD. This will be discussed in further detail below.

Table 3-2 presents a comparison of the WMA approved withdrawal volumes, the total approved maximum daily withdrawal rate and the ADD. This table shows that based on the current ADD, the Parker River Basin was underutilized, which can be attributed to poor water quality in the Brown's well and decreased storage volume in the reservoir system because of low rainfall. As mentioned above, in 2016, the Town exceeded its WMA authorization in the Ipswich River Basin, with permission from DEP.

Table 3-2. Summary of Water Supply Sources

River Basin	WMA Withdrawal Volume (MGD)	Approved Maximum Withdrawal Rate (MGD)	ADD (MGD) (2012-2016)
Parker River Basin (Reservoirs and 2 wells)	0.98	1.44	0.74
Ipswich River Basin (3 active wells)	0.20	0.75	0.27
Total	1.18	2.19	1.01

Table 3-3 presents the current and future estimated ADD compared with the WMA authorized withdrawal rate and the current available withdrawal capacity.

Table 3-3. Water Demands vs. WMA Withdrawal Volumes and Restricted Withdrawal Volumes

Year	ADD (MG)	WMA Annual Authorized Withdrawal Rate (MGD)	Difference Between the ADD and the WMA Withdrawal Rate (MGD)	Restricted Withdrawal Capacity (during drought conditions) (MGD)	Difference Between the ADD and the Restricted Withdrawal Capacity (MGD)
2012-2016	1.01	1.18	0.17 Surplus	0.96	0.05 Deficit
2040 (48 RGPCPD)	1.11	1.18	0.07 Deficit	0.96	0.15 Deficit
2040 (65 RGPCPD)	1.39	1.18	0.21 Deficit	0.96	0.43 Deficit

The WMA annual authorized withdrawal rate is sufficient for the Town's current demands. However, future demand projections exceed the WMA annual authorized withdrawal rate by 0.21 MGD. Therefore, the Town will need to request an increase in their WMA limit. The next opportunity to do so may come as early as 2023, when DEP expects to renew the WMA Permits for the Parker River Basin.

To summarize, the restricted water-supply capacity of 0.96 MGD during drought conditions is not sufficient to meet the current demands. There is a deficit of 0.05 MGD. To meet the projected future average-day demand, the Town will need to maintain the capacity of its existing sources and increase its water supply by approximately 0.43 MGD.

Section 2 also presented the current MDD of 3.04 MGD and the future MDD of 4.17 MGD projected to occur in 2040. The current system pumping capacity is reported to be 4.27 MGD. The MDD represents a short-term demand that depends more on treatment and pumping capacity than Firm Yield. Based on current available pumping capacity, the existing system should be able to meet the MDD in 2040.

3.1 Reservoir System Firm Yield

The Ipswich reservoir system includes two sources: the Bull Brook and Dow Brook Reservoirs. These sources are interconnected and provide water to the Ipswich WTP. The Safe Yield of the reservoir system was calculated in 1988 and estimated to be 0.8 MGD. The Safe Yield was based on the 1 in 20 year drought (a drought that statistically may occur once every twenty years), as determined using another consultant's Reservoir Storage-Yield Computer Simulation Model (RESSIM). This Safe Yield is documented in the WMA permit for the Parker River Basin. Per the permit, withdrawals for Dow and Bull Brook Reservoirs must not exceed 0.8 MGD as an annual average.

Due to concerns with the capacity of the reservoirs experienced during the 2016 drought period, part of the scope of this study was to recalculate the Safe Yield of the reservoir system based on updated hydrologic and bathymetric data. As noted above, when researching the latest methods for calculating the Safe Yield and through conversations with DEP, we found that historically the terms Firm Yield and Safe Yield had been used interchangeably. [Ref: D. LeVangie, DEP] However, currently the term Safe Yield is not in use for reservoirs, but only used to refer to the yield of the Commonwealth's major river basins. Firm Yield is the term now used when referring to the capacity of a reservoir or reservoir system. DEP also noted that there was no specific guidance on how to calculate a reservoir's Firm Yield (previously called Safe Yield) until the late 1990s/early 2000s. Prior to the late 1990s, consultants and water suppliers had their own approaches for calculating Safe Yield/Firm Yield. In the 2000s, DEP and the US Geological Survey (USGS) formalized a methodology for calculating Firm Yield. The latest USGS Firm Yield methodology is described in its report entitled "Refinement and Evaluation of the Massachusetts Firm-Yield Estimator Model Version 2.0", which is available at: https://pubs.usgs.gov/sir/2011/5125/.

The DEP currently uses the following definition for Firm Yield:

Firm Yield means a simulated estimate of the water volume available in a reservoir or reservoir system during drought conditions, as approved by the Department. Firm Yield is determined using the response of the reservoir to the drought of record. If the applicant has a drought management plan that details specific steps to be taken in response to droughts and the means to measure results, the Department will consider the response of the source(s) to the best approximation of a 1-in-20 year drought. The reservoir system's firm yield derived from this analysis will then become the basis for permitting maximum annual withdrawals from the reservoir(s).

AECOM requested information on the methodology for identifying the 1- in 20-year drought. According to DEP, the early 1980s was considered approximately a 1- in-20 year drought for Massachusetts. However, it was never defined. DEP noted that for those suppliers interested in a higher Firm Yield, the supplier can manage to a less severe drought provided they have a detailed plan. The USGS Firm Yield Estimator does calculations for the 1960's drought, the 1980's drought and the 2002 drought, in that order. The impact of the drought varies across the state, but generally the 1960's drought was more severe and it was quite long (9 years), so it has the biggest impact on reservoirs. The impact of the drought that occurred in the 1980's and 2002 varies in length and severity across the state. Both droughts lasted about 2-3 years. DEP noted that the 1980's or 2002 droughts could be used for evaluation purposes.

3.1.1 Description of Firm Yield Model

The Firm Yield of the Dow Brook and Bull Brook reservoir system was estimated by AECOM based on the methodology outlined in *Estimating the Firm Yield of a Surface Water Reservoir Supply System in Massachusetts: A Guidance Document, Version 1.0* prepared by the Water Management Program, (DEP), Office of Watershed Management, January,1996, and the USGS Firm Yield report and methodology entitled *Refinement and Evaluation of the Massachusetts Firm-Yield Estimator Model Version 2.0* was also used as a reference.

The following is a list of the main data components used in AECOM's Firm Yield model:

- Daily streamflow and precipitation data for 1960 to 2017 from the USGS Station on the Parker River at Byfield (USGS 01101000).
- Bathymetric survey data of Dow and Bull Brook Reservoir by CR Environmental (2018). This data was used to calculate the storage volume of each reservoir and estimate the reservoir volume and area versus elevation relationships for each reservoir.
- Monthly peak use factor to reflect seasonal demands.
- Hydraulic constraints impacting the reservoirs, for example, the 36-inch diameter diversion pipe from Bull Brook Reservoir to the Dow Brook Reservoir and the 14-inch diameter connection to the raw water pump station.

3.1.2 Bathymetric Survey

CR Environmental, Inc. (CR) performed bathymetric surveys of the Bull Brook and Dow Brook Reservoirs on April 11th to 12th, 2018 and May 17th to 18th, 2018, respectively. The purpose of the surveys was to estimate the storage volume of each reservoir and identify the hypsographic relationships, which include the relationships between reservoir volume and area, and reservoir volume and elevation. In addition, sediment accumulation was assessed. Surveys were conducted using a 12-foot aluminum skiff, powered by an electric motor. The skiff was equipped with a small instrument enclosure and power supplies for computers and survey electronics.

Table 3-4 presents the observed water-level elevation, reservoir surface area, maximum depth, average depth and estimated full-pool capacity for each reservoir. Table 3-5 presents a summary of the storage volumes as originally documented and the storage volumes estimated through the 2018 bathymetric survey data. The 2018 storage volume in the Dow Brook Reservoir was found to be 51.7 MG at full pool and 60.98 MG at the top of flashboards (the storage volume with flash boards of 60.98 MG was used in the Firm Yield model). The 1988 full pool storage volume in the Dow Brook Reservoir was 53.1 MG. The reservoir volume with flashboards was 64 MG based on historical information provided by the Town. Therefore, the 2018 storage volume with the flash boards is approximately 3.1 MG less than what was documented in 1988.

The Bull Brook Reservoir storage volume in 2018 was found to be approximately 11.0 MG less than originally documented in 1988. These values represent a total reduction in storage volume of 14.1 MG for the reservoir system. Bathymetric survey figures for each reservoir are presented in Appendix A. The figures show the elevation of the bottom of the reservoir.

Table 3-4. 2018 Bathymetric Survey Data

	Bull Brook Reservoir	Dow Brook Reservoir
Observed Water Level	0.02 feet above spillway or El. 34.6 ft NAVD88	0.02 feet below spillway or El. 30 ft NAVD88
Reservoir Surface Area	10.75 acres	17.35 acres
Maximum Depth	11.8 feet	20.4 feet
Average Depth	4.8 feet	8.4 feet
Estimated Full Pool Capacity	16,432,000 gallons	60,986,000*

*Dow full pool capacity includes the flashboards.

Table 3-5. Reservoir System Storage Volumes

	1988 Reported Storage Volume (MG) at Full Pool	2018 Bathymetric Survey Storage Volume (MG) at Full Pool	Storage Volume Difference(MG)
Dow Brook Reservoir	64.0	60.9	3.1
Bull Brook Reservoir	27.4	16.4	11.0
Total	87.8	77.3	14.1

3.1.3 Firm Yield Model

The determination of the Firm Yield of a reservoir is a mass balance that accounts for inflows and outflows to the water body/drainage area, including: streamflow, precipitation, evaporation, groundwater flow, demand, required releases, and withdrawals by others. The governing equation is the conservation of water mass for an incompressible fluid. AECOM prepared the system-yield model to reflect recently acquired daily streamflow and precipitation data, hydraulic constraints, and bathymetric survey data. The model is described in the sections below.

Stream Flow and Precipitation Data

Stream flow and precipitation data are used to estimate the inflow into each of the reservoirs. Daily streamflow data was obtained from the USGS National Water Information System for the Parker River Station at Byfield (USGS Station 01101000). This is the same stream gauge and procedure used for other studies conducted by AECOM in the area, and was previously approved by DEP. The streamflow data is entered into the spreadsheet. The ratio of the Parker River basin drainage area to the Bull Brook and Dow Reservoir drainage areas was used to calculate the streamflow contribution to the reservoirs.

Daily precipitation data from January 1, 1960 through December 31, 2008 were obtained from the NOAA National Climate Data Center (http://www.nndc.noaa.gov) for station USC00193879 located in Ipswich, Massachusetts. Daily precipitation data from January 1, 2009 through July 31, 2017 were obtained from the Town. This precipitation data was compared to information from Beverly, MA and found to be similar.

The period evaluated was 1962 through July 31, 2017. Figure 1 presents the annual precipitation over this period. The annual average rainfall during that period is 52.5 inches.

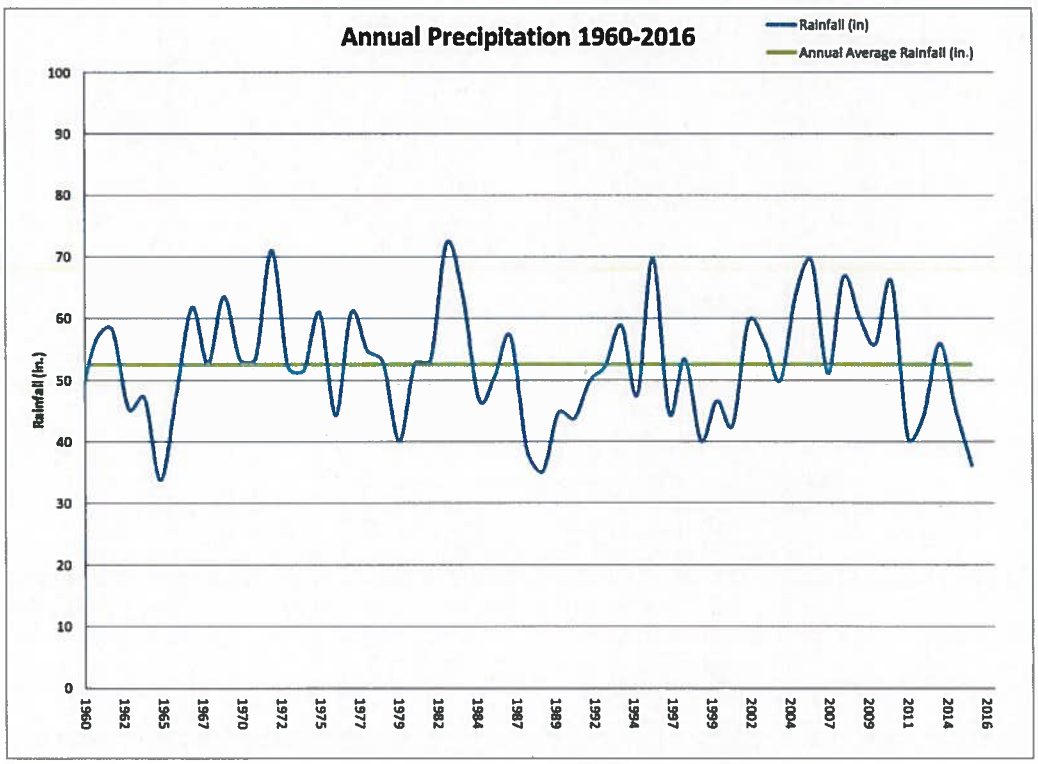


Figure 3-1. Annual Precipitation 1960-2016

Monthly Peak Use Factor

Seasonal demands within the water system affect the resultant Firm Yield of the reservoir. DEP requires that a monthly peak-use factor be established to better represent realistic increased withdrawals during the summer months (when inflows are low), and reduced withdrawal rates during the winter months (when inflows are higher).

Peak-use factors were calculated using monthly Ipswich pumping data. The period 2012 through 2016 was used to determine the mean monthly withdrawal for each month. A summary of the average withdrawal over the sample period and the calculation of the peak-use factors are presented in Table 3-6.

Table 3-6. Annual Peak Use Factor for Ipswich

Month	Avg. Withdrawal Over the Period 2012 – 2016 (gal)	Peak Use Factor
January	25,393,072	0.8703
February	23,405,919	0.8023
March	25,825,510	0.8851
April	28,125,375	0.9639
May	33,931,792	1.1629
June	33,148,010	1.1361
July	35,824,326	1.2278
August	34,099,564	1.1687
September	29,551,677	1.0128
October	27,874,219	0.9553
November	26,269,532	0.9003
December	26,689,417	0.9147

Hydraulic Constraints

The existing hydraulic constraints used in the Firm Yield evaluation included: the diversion pipe between the Bull Brook Reservoir and Dow Brook Reservoir, the spillway structures at the Bull Brook and Dow Brook Reservoirs, the raw water intake at the Dow Brook Reservoir, and the raw water pumps at the Ipswich Water Treatment Plant pump station.

The constraints for this system yield model were evaluated as follows:

- The 36-inch diameter diversion pipe at elevation of 29.0 NAVD 88 at Bull Brook Reservoir. The Hazen-Williams Equation was used to calculate the head loss between Bull Brook Reservoir and Dow Brook Reservoir. Manning's Equation was used to calculate maximum flow through the diversion pipe when the water elevation drops below 32.0 NAVD 88 (Open Channel). The spillway at Bull Brook Reservoir is a concrete ogee shaped structure fitted with two, 4-feet wide by 1-foot high flashboards at the crest of the spillway; the spillway elevation is 34.4 NAVD 88. The low water surface elevation in Bull Brook Reservoir was set to 30.0 NAVD 88 to leave at least 1 foot water elevation in diversion pipe.

- The 36-inch diameter diversion pipe at elevation of 26.39 NAVD 88 at Dow Brook Reservoir. The elevation of the gatehouse drain is at 12.2 NAVD 88. The low water surface elevation in Dow Brook Reservoir was set to 12.2 NAVD 88 to leave the gatehouse drain full at all times.

Table 3-7 presents the maximum usable storage per reservoir with constraints.

Table 3-7. Maximum Usable Storage Per Reservoir

	System Yield		
Reservoir	Maximum Water Surface Elevation (ft)	Intake Pipe Invert Elevation (ft)	Maximum Usable Storage (Gal)
Dow Brook	31.8$^{(1)}$	26.39	60,695,000
Bull Brook	34.4$^{(2)}$	29.0	11,903,000

1. Top of Flashboards
2. Spillway Full Pool

Reservoir Storage vs Surface Area Curves and Reservoir Storage vs Stage Curves

The May 2018 bathymetric data was used to develop the reservoir storage-surface area curves and storage-stage curves for each of the reservoirs. These curves are presented in Appendix B. The reservoir curves and reservoir storage-stage curves have been further defined by equations using least squares regression to relate the surface area and storage in the reservoir to the available active storage. The best fit equations of the reservoir storage-surface area curves are also presented in Appendix B. These equations are used to simulate how the watershed area changes as the reservoir water level changes.

Result

The system yield model was run to estimate the Firm Yield of the reservoir system. As discussed in Section 3.1, the Firm Yield for reservoirs located in this area is typically based on the drought of the 1960's. However, as this evaluation was conducted, we found that the model for the Dow and Bull Brook reservoir system fails first during the drought of 2016. Table 3-8 presents the 12 lowest calculated Firm Yields based on rainfall conditions that caused the reservoir system to fail from 1965 through 2016. This information is presented in chronological order. The drought that occurred in 2016 resulted in the lowest Firm Yield of 0.41 MGD, therefore this period is considered to be the worst drought of record in the Town of Ipswich. The drought in the 1960's resulted in the second lowest yield of 0.45 MGD and the drought in 1997 resulted in the third lowest yield of 0.47 MGD. Table 3-8 also presents the dates on which the model predicts the reservoir-system would fail. The model predicts that the reservoir-system most often fails in October, November, and December.

Table 3-8. 2017 Reservoir Yield Results

Drought Year	Firm Yield (MGD)	Failure Date	Rainfall Total (in)
1965	0.45	12/25/1965	33.73
1983	0.65	10/21/1983	72.24
1993	0.51	10/31/1993	52.39
1995	0.50	10/21/1995	48.08
1997	0.47	11/2/1997	44.61
1999	0.56	9/16/1999	39.98
2001	0.48	12/16/2001	42.75
2002	0.64	11/16/2002	59.49
2007	0.64	10/31/2007	51.70
2010	0.57	10/31/2010	55.88
2012	0.66	10/28/2012	40.75
2015	0.60	12/14/2015	45.16
2016	0.41	11/14/2016	35.85

The model results indicate that the reservoirs normally spill more than half of the year, but not normally during May or June through October of each year. Figure 3-2 presents the fluctuations in the storage volume for Bull and Dow Brook Reservoirs, and the spill volume for Dow Brook Reservoir from June 2009 through July 2017, as predicted by the Firm Yield model. The model predicted the Dow Brook Reservoir failure in November of 2016. It also predicted that the Dow Brook Reservoir normally loses a significant amount of water over the spillway each year during the late fall, winter, and early spring, indicating that there is available water supply that the reservoir is unable to store. Both reservoirs have returned to full capacity each year. The reservoir-system is much more sensitive to the timing of the rainfall, specifically, the months of late spring, summer, and fall. The figure shows Bull Brook Reservoir with periods of zero volume most years, which indicates that the water level in Bull Brook Reservoir is below the invert of the transfer pipe entrance.

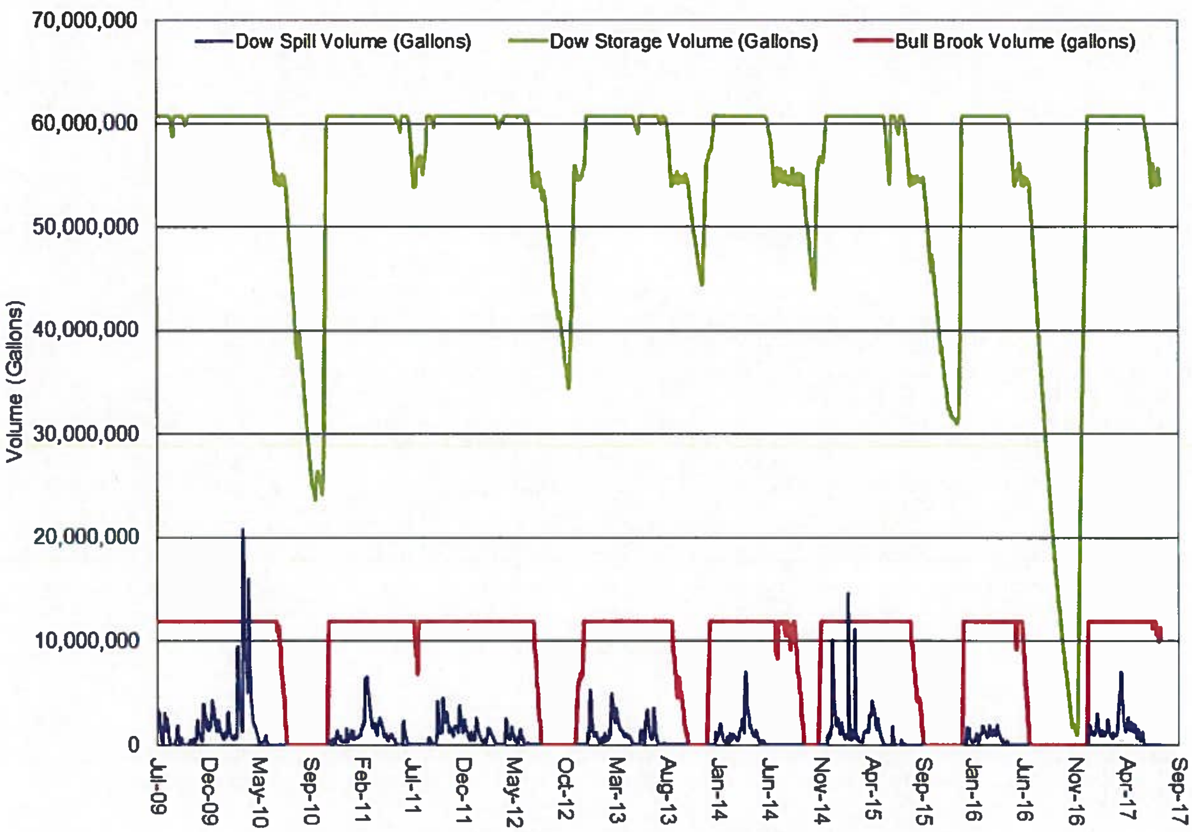


Figure 3-2. Reservoir System Storage and Spill Volumes

Figure 3-3 and Table 3-9 present a comparison of the monthly rainfall data for 1965, 2001, 2012 and 2016. In 1965, the total rainfall was 33.73 inches and the rainfall in 2016 was 35.85. Based on these annual totals, one might expect that the model would predict reservoir failure in 1965 before 2016. However, based on available rainfall data, more rain fell in the January to April time period in 1965 (16.17 inches) compared to 2016 (13.52 inches). Approximately 7 inches of rain fell from May to August for both periods. This observation suggests that the available capacity of the reservoir system is dependent on the timing of rainfall through the year. And, as mentioned above, the reservoir-system storage is low compared to its drainage area. Therefore, there is insufficient storage capacity within the reservoir system to take advantage of high runoff periods during the typical wet time of the year.

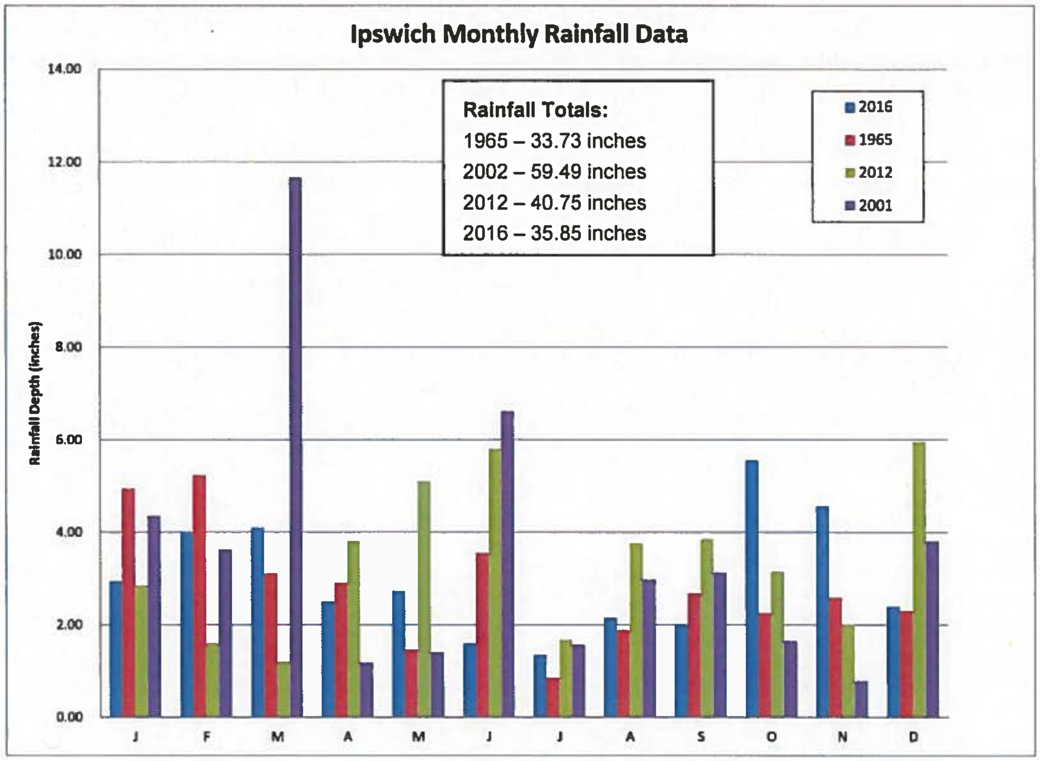


Table 3-9. Monthly Rainfall Data for 1965, 2001, 2012 and 2016

	Rainfall (inches)			
Date	**2016**	**1965**	**2012**	**2001**
January	2.94	4.94	2.85	4.35
February	3.98	5.23	1.60	3.62
March	4.10	3.10	1.20	11.66
April	2.50	2.90	3.80	1.18
May	2.72	1.46	5.10	1.41
June	1.60	3.55	5.80	6.61
July	1.35	0.85	1.68	1.57
August	2.15	1.88	3.77	2.98
September	2.00	2.67	3.85	3.13
October	5.55	2.26	3.15	1.65
November	4.56	2.59	2.00	0.78
December	2.40	2.30	5.95	3.81
Total	**35.85**	**33.73**	**40.75**	**42.75**
January to June	17.84	21.18	20.35	28.83
July to December	18.01	12.55	20.40	13.92
January to April	13.52	16.17	9.45	20.81
May to August	7.82	7.74	16.35	12.57
September to December	14.51	9.82	14.95	9.37

Based on the foregoing, AECOM concludes that the 2016 drought was the drought of record, and the Firm Yield for the reservoir system is 0.41 MGD. This is a significant finding, though it tends to confirm the Town's experience with the reservoir-system over the years. We should point out that the Firm Yield represents the average-annual capacity of the reservoir-system during the drought of record. In other words, if a drought like the one of 2016 were to recur, the capacity on any particular day (in late summer, for example) might be less than 0.41 MGD.

3.1.4 Minimum Release Requirements

The Ipswich Reservoir System does not have a minimum-release requirement per the WMA permit. According to the September 22, 2017 DEP letter to the Parker River Basin WMA Permittees, new methods for calculating minimum-release requirements will be in the new permits.

4 Screening of Options for New Water Supply Sources or Expansion of Existing Sources

Since current demands and the future demand projections show that the Town is exceeding the available capacity of current supplies, additional sources of drinking water need to be located. The purpose of this screening evaluation is to assess opportunities to increase the available water supply for the Town. The increase could be accomplished by adding new sources, expanding existing sources, or a combination of both. AECOM and the Town developed the following list of seven potential new or expanded sources to be evaluated: (After an initial review, AECOM and the Town decided to add an eighth option which includes increasing raw water storage by adding large storage tanks.)

1. New Well Field(s)
2. Reservoir Expansion - Raising Existing Dams
3. Reservoir Expansion - Excavating Around Reservoirs/Removing Sediment
4. Reservoir Expansion - Building New Upstream Dams
5. Reservoir Expansion- Building Storage Tanks
6. Desalination
7. Wastewater Reuse
8. Interconnections with Surrounding Communities

The approximate locations assumed for preparation of this report for each of the potential sources are presented in Figure 4-1.

Figure 4-1. Approximate Locations for Potential Sources

The first step in this evaluation was to conduct an initial screening with a goal of identifying the three most advantageous options from the list above for further investigation. Sections 4.1 through 4.5 provide a description of the potential sources and a discussion of each of the screening criteria. These screening criteria include: potential capacity gained, technical feasibility, permit requirements, stakeholder concerns, treatment requirements, additional staffing needs, concept-level cost and schedule for implementation. The results of the evaluation and the three options recommended for further investigation are provided in Section 4.6.

During the screening process, we inevitably had to make certain assumptions and judgements where information on each of the screening criteria was incomplete. AECOM worked closely with the Town, especially where information was scarce or where the Town had considered certain options in the past.

4.1 New Groundwater Supplies

AECOM has been conducting test-well investigations for the Town of Ipswich since early 2016. Based on these investigations, a new source at the Lynch Well Site and upgrades at the Browns Well site (from 200 to 400 gpm) were considered to be the most promising. AECOM recommended that the Town take the necessary steps to permit the Lynch Site for a new source of municipal water supply in a December 5, 2017 letter, titled, "Favorability of Lynch Property for New Source of Municipal Water Supply" (See Appendix C).

The Lynch Well Site was initially investigated in 2016. In 2018, it was subjected to a 15-day pumping test under DEP's New Source Approval process. DEP is currently reviewing the New Source Final Report. AECOM estimates that the Lynch Site could produce up to 510 gpm or 0.73 MGD. . The Browns Well replacement well investigation was documented in a letter report to Ms. Vicki Halmen dated March 31, 2016. The report concluded that a replacement well for the Browns well could produce up to 400 gpm, or 0.58 MGD, which equates to a 0.38 MGD increase in yield based on the restricted capacity of 0.2 MGD. However, only 0.29 MGD of this restored capacity could be utilized under the current authorized maximum withdrawal rate of 0.49 MGD for Browns Well.

4.1.1 Potential Capacity

Table 4-1 summarizes the potential capacity of each of the new or expanded well sites. Both of the potential wells are all located in the Parker River Basin.

Table 4-1. Potential New or Expanded Well Sites

New Source	Potential Capacity
Lynch Well Site	0.73 mgd
Browns Well Replacement	Restore from 0.2 mgd to 0.49 mgd (which equates to a 0.29 mgd increase)

Well options provide immediately available water, and enhance operational flexibility during drought or equipment failure at other source locations. They also provide redundancy to the WTP. As stated above, the Lynch Site could produce up to 0.73 MGD. A replacement Browns Well could produce up to 0.58 MGD, an increase of 0.28 MGD over the existing Browns Well. The capacity of the aquifer at the Browns Well has been demonstrated through years of pumping.

4.1.2 Technical Feasibility/Treatment Requirements/Staffing Needs

The Lynch well site would require the construction of four wells and a pumping facility, and land acquisition to meet the Zone 1 requirements. The Browns Well Replacement would require the construction of the replacement well and modifications to the existing pumping facility. Due to high manganese levels, the Browns Well option would also require either construction of a greensand filtration plant or a transmission main extending from the well to the existing WTP. The Browns Well water quality was analyzed in the Ipswich Wells Action Plan for Manganese Control prepared by AECOM in June 2014. Both well options would require treatment for corrosion control, chlorination, and fluoride addition, which can be performed at the well station. The Lynch and Browns well sites would have the same staffing requirements, which include daily inspection of the wells and pumping facilities. Since Browns well is an existing well, additional staffing would only be required if a greensand plant is constructed to provide additional treatment. Additional staffing could be minimized by designing the new facility to operate as a satellite WTP per DEP's guidelines and policies for unattended operation.

4.1.3 Permitting

The Lynch Well site is currently in the DEP New Source Approval process. The New Source Final Report was submitted to DEP in December 2018. In addition, an Environmental Notification Form (ENF), and a Water Management Permit Amendment application were submitted at the same time. Permit applications to Construct Wells and Pumping Facilities would have to be filed with DEP. In addition, wetlands permits would likely be required. The Browns Well Replacement project would be subject to the DEP replacement well process and would require DEP Permit applications to Construct Wells and Pumping Facilities. Wetlands permitting would be likely. Additional permitting could also be required for the construction of the new greensand water filtration plant or for the transmission main.

4.1.4 Stake Holder Concerns

The stake holders for each of these potential well sites would include the watershed associations, the Ipswich school department, and the local property owners, including the local farmers. The watershed associations typically have concerns about streamflow depletion, and related environmental impacts. The Town may need to restrict salt and fertilizer application near the Lynch well, if it becomes a new source of supply. The application of salt and fertilizer in the area of the well could have a negative impact on the water supply. Local farms in the area withdraw water from the watershed upstream of the Lynch Site. The Browns Well is an existing well, therefore, it is not anticipated that there will be new impacts to the stakeholders, if the well is replaced. Browns well water has high levels of manganese. One possible cause of the high manganese levels is a build-up of standing water and decomposing leaves, creating anoxic conditions near the well. Flooding of the clay pit pond behind the well, enhanced by beaver dams in the area, probably plays a role in the manganese problem. AECOM has suggested that manganese levels in the Browns Well could decline if the dams and beaver were removed. The Town has DEP authorization to remove beaver and beaver dams near the Browns Well. However, permission from the Conservation Commission is still required.

4.1.5 Schedules

The Lynch Well could be operational within 2 years (end of 2020), since the New Source Approval process is nearly complete. The Browns Well site could be operational within 2 years of initiating the well replacement process with DEP if a greensand treatment plant is not required. If a greensand treatment plant is required the site could be operational in 4 years. A transmission main could be constructed in parallel with constructing the new wells, however, a treatment plant would likely take longer to construct.

4.1.6 Concept Level Opinion of Costs

As previously mentioned, AECOM has been investigating adding new wells or replacing wells for the Town of Ipswich since 2016. For this reason, concept level opinion of costs have been prepared as part of those efforts. Below is a summary of the estimated costs of each well project, including the year the opinion of costs was developed.

Lynch Well Site:

As part of the January 17, 2017 Test Well Investigation report, AECOM developed a concept-level opinion of costs for testing, permitting, design and construction of four new wells and related pumping facilities and transmission mains at the Lynch property of $2.8 million (January 2017 dollars). Using the Engineering News Record (ENR) Construction Cost Index (CCI) this estimate is equivalent to $2.96 million in July 2018. This does not include the cost for land acquisition of approximately 0.5 acres.

Browns Well:

In the March 31, 2016 letter report on Browns Well, AECOM's concept-level opinion of cost for the design, permitting and construction of a replacement well and related pumping facilities is $575,000 in April 2016 dollars. Using the ENR CCI, this estimate is equivalent to $625,000 in July 2018.

The Ipswich Wells Action Plan for Manganese Control prepared by AECOM in June 2014 presented a concept level opinion of cost for a greensand filtration plant of approximately $4 million in June 2014 dollars. Using the ENR CCI, this estimate is equivalent to $4.5 million in July 2018 dollars.

The concept level opinion of cost for a one-mile long transmission main extending from the well to the existing WTP or to the reservoirs would be approximately $1.0 million in July 2018 dollars.

4.1.7 New Groundwater Supplies Advantages and Disadvantages

Advantages

- The New Source Approval process for the Lynch Well Site is underway; the Well Site is capable of producing 510 gpm, or 0.73 MGD;
- Well options provide immediately available water, and enhance operational flexibility during drought or equipment failure at other source locations.
- Some wells provide redundancy to the WTP and can be operated independently, reducing staffing costs
- Browns well site has a proven capacity of 400 gpm or 0.58 MGD; a replacement well will require minimal permitting.

Disadvantages

- Development of the Lynch site will require additional water-quality investigations, additional hydrogeologic investigations, and negotiations with nearby landowners.

- The Browns site may require a greensand filter or the construction of a transmission main to the water treatment plant.
- Both wells require treatment for corrosion control, chlorination and fluoride addition.

4.2 Reservoir Expansion

The Ipswich Reservoir system includes the Bull Brook and the Dow Brook reservoirs. Water from the Bull Brook Reservoir is transferred to the Dow Brook Reservoir by gravity via a 36-inch diameter diversion pipe, and then from the Dow Reservoir, the water is pumped to the WTP. During recent (2016) drought conditions, the water level in the Bull Brook and Dow Brook Reservoirs drew down, leaving only a stream in some locations. This reduction in storage limited the available water supply to the Town. A picture of the Bull Brook Reservoir during the summer of 2016 is presented in Figure 4-2.

Figure 4-2 Bull Brook Reservoir Summer 2016

The storage volume in Bull Brook Reservoir is currently 16.4 MG and the storage volume in Dow Brook Reservoir is approximately 60.98 MG (with flashboards installed) which is a combined storage volume of 77.3 MG. These storage volumes were calculated by CR Environmental, Inc. based on bathymetric surveys of each reservoir conducted in the spring of 2018. It should be noted that the storage volume in the Bull Brook Reservoir was previously thought to be 27 MG, so the new measurements represent a decrease in the storage volume of 11.0 MG. The new bathymetric survey also showed a small decrease in the storage volume of 1.4 MG in the Dow Brook Reservoir. The Table 4-2 presents the existing elevations and storage volumes of the Dow and Bull Brook Reservoirs.

Table 4-2. Dow and Bull Brook Reservoir Statistics

	Bull Brook Reservoir	Dow Brook Reservoir	Combined Storage Volume (MG)
Dam Elevation	35	32.5	--
Surface Area (acres)	15.00	18.00	--
Watershed Tributary Area (square miles)	3.07	0.97	---
Storage Volume (MG) Based on 2018 Bathymetric Survey Data	16.4	60.98	77.38
Storage Volume (MG) Based on Historical Data	27.4	64.0	88.4

The watershed areas and storage volume for each of the reservoirs were reviewed to establish if the reservoirs were properly sized and if there was additional water available to be stored. Historical observations show that during wetter months, which typically include November through April, the reservoirs fill very quickly, and the water overtops the dam spillways after a few months of rain. These observations indicated that there may be potential water available for additional storage. In addition, studies conducted by AECOM in the 1960s found that, in New England, for every square mile of watershed area, there is typically 200-300 MG of available water that could be stored. Using the combined watershed area for the reservoir system of 4.04 square miles, the potential available water volume to be stored can be estimated to be 800 to 1200 MG. From this analysis, we can conclude that the reservoirs are undersized, given the watershed areas, and could potentially be expanded to increase storage volume.

The following four potential modifications to the reservoirs to increase the available storage volume were reviewed:

1. Reservoir Expansion - Raise Existing Dams
2. Reservoir Expansion – Build Storage Tanks
3. Reservoir Expansion - Excavate Around Reservoirs/Remove Sediment
4. Reservoir Expansion - Build New Upstream Dams

4.2.1 Reservoir Expansion – Raise Existing Dams

Raising the dams at each reservoir was considered to increase storage volume. This increase was evaluated as part of the Firm Yield analysis and is presented below.

4.2.1.1 Potential Capacity and Impacts

To evaluate the impacts of increasing the storage volume in the reservoir system by raising each of the dams by 2 feet, CR Environmental, Inc. (CR) performed an analysis using LiDAR point data and the existing bathymetric survey data to generate a seamless digital elevation model (DEM) of the reservoirs and surrounding terrestrial landscape. For both reservoirs, the DEM was used to calculate the extent of inundation and volume increase associated with raising the dams' full-pool elevation by 2 feet.

For Bull Brook Reservoir, the maximum hypothetical elevation was 36.4 feet NAVD88, 2.0 feet above the spillway. The calculated hypothetical maximum volume for Bull Brook Reservoir was 27.6 MG. The hypothetical inundation area was 1,078,404 square feet. These calculations assume a secondary control structure to prevent flooding of the existing WTP. For Dow Brook Reservoir, the maximum hypothetic elevation was 33.8 feet NAVD88, 2.0 feet above full-pool with flashboards installed. The hypothetical maximum volume for Dow Brook Reservoir was 74.2 MG. The usable storage volumes provided in Table 4-3 below are less due to piping arrangements at the reservoirs. The hypothetical inundation area was 979,149 square feet.

Firm Yield Estimate

To estimate the increase in Firm Yield, the firm yield model was updated to include the new data. New Reservoir Storage vs Surface Area Curves and Reservoir Storage vs Stage Curves were generated.

Based on the analysis, AECOM estimated that raising the dams at both reservoirs by 2 feet could increase the Firm Yield from 0.41 to 0.49 MGD, which is an increase of approximately 0.08 MGD. Table 4-3 presents a summary of the existing and proposed water surface elevations, surface area and total usable storage for each reservoir. In addition the Firm Yield for the reservoir system under both conditions is presented.

Table 4-3.Dow and Bull Brook Reservoir System Storage Volumes

	Existing		Proposed (Raise dam elevations 2 feet)		Percent Increase	
	Dow	Bull	Dow	Bull	Dow	Bull
Water Surface Level (ft)	31.8	34.4	33.8	36.4	6%	6%
Surface Area (SF)	801,068	468,270	979,149	1,078,404	22%	130%
Total Usable Storage (Gallon)	60,695,000	11,903,000	73,818,000	23,032,000	22%	93%
Combined Storage Volume (gallons)	72,598,000		96,850,000		27%	
Yield (MGD)	0.41		0.49		21%	

The Firm Yield with additional storage is 0.49 MGD, 20 percent greater than existing condition. Figure 4-3 presents the model results for the Dow and Bull Brook Reservoir storage volumes, with and without raising the spillways by 2 feet.

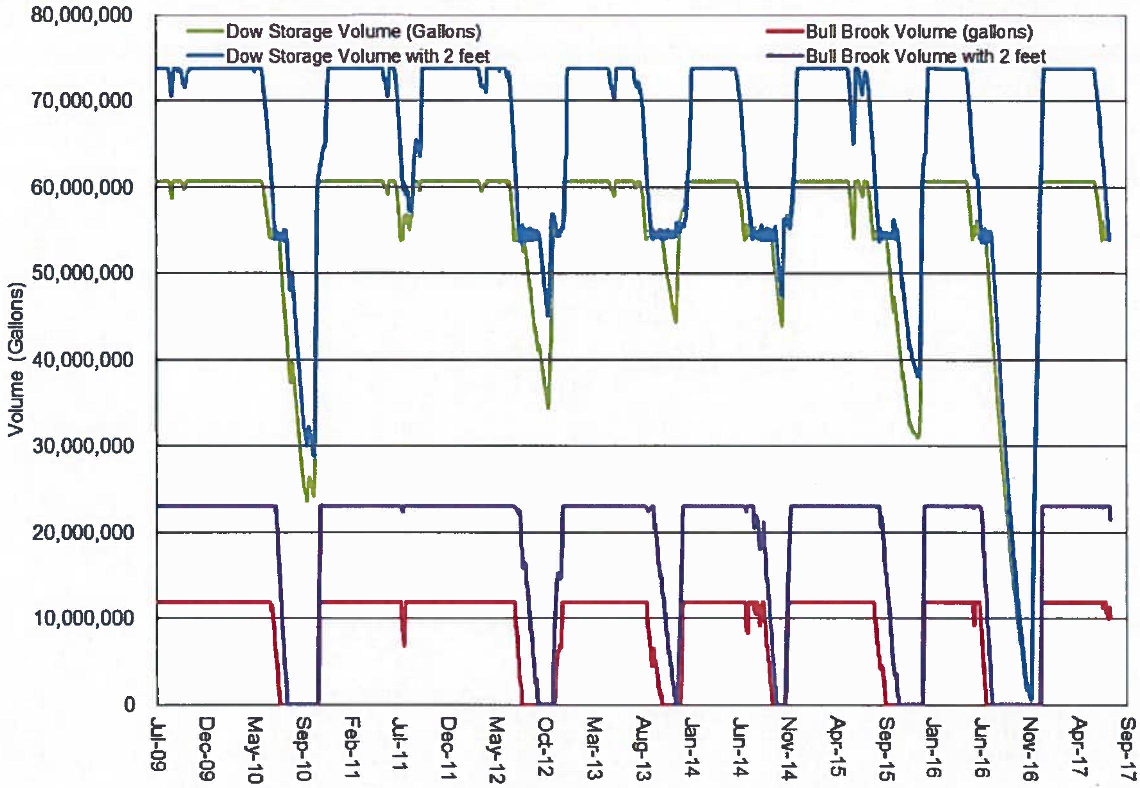


Figure 4-3. Dow and Bull Brook Reservoir Storage Volumes with and without Raising Spillways by 2 Feet

Figures 4-4 and 4-5 present the water surface areas at various water surface elevations for Dow Brook and Bull Brook Reservoirs, respectively. These maps were also used to identify Natural Heritage and Endangered Species (NHESP) habitats in the vicinity of the reservoirs by comparing our maps to the NHESP GIS maps. Our initial review found that there are no NHESP habitats located in the project area.

The initial assessment of the Dow Brook Reservoir showed that raising the dam 2 feet could flood private property on the north side of the reservoir along High Street. Berms/dikes could be installed to minimize impacts. The initial assessment of the topographic map in the area of the Bull Brook Reservoir showed that raising the dam 2 feet could potentially flood Mile Lane where it crosses over a wooded marsh on the east side of the reservoir. This impact could be mitigated by raising the elevation of the roadway. In addition, the wooded wetlands would also be flooded so those impacts would also need to be mitigated.

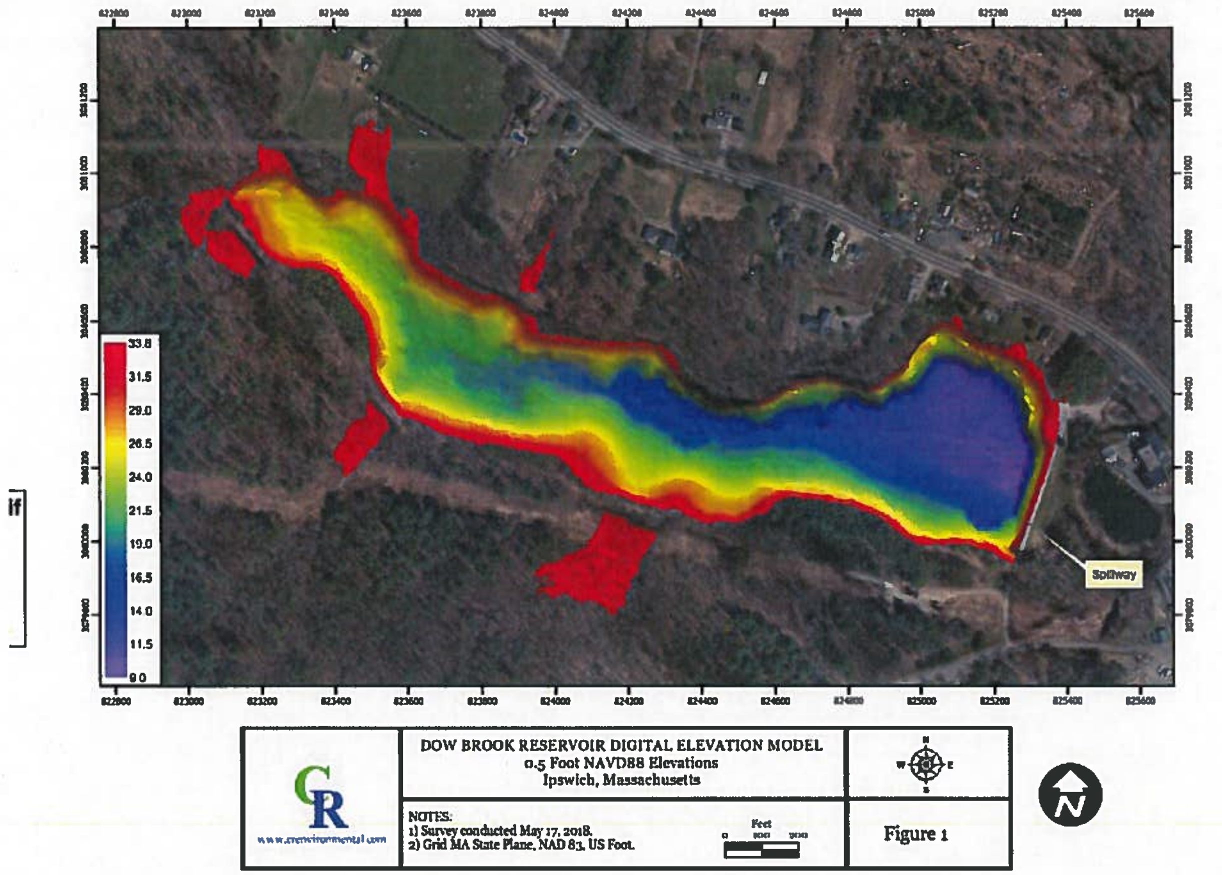


Figure 4-4. Dow Brook Reservoir

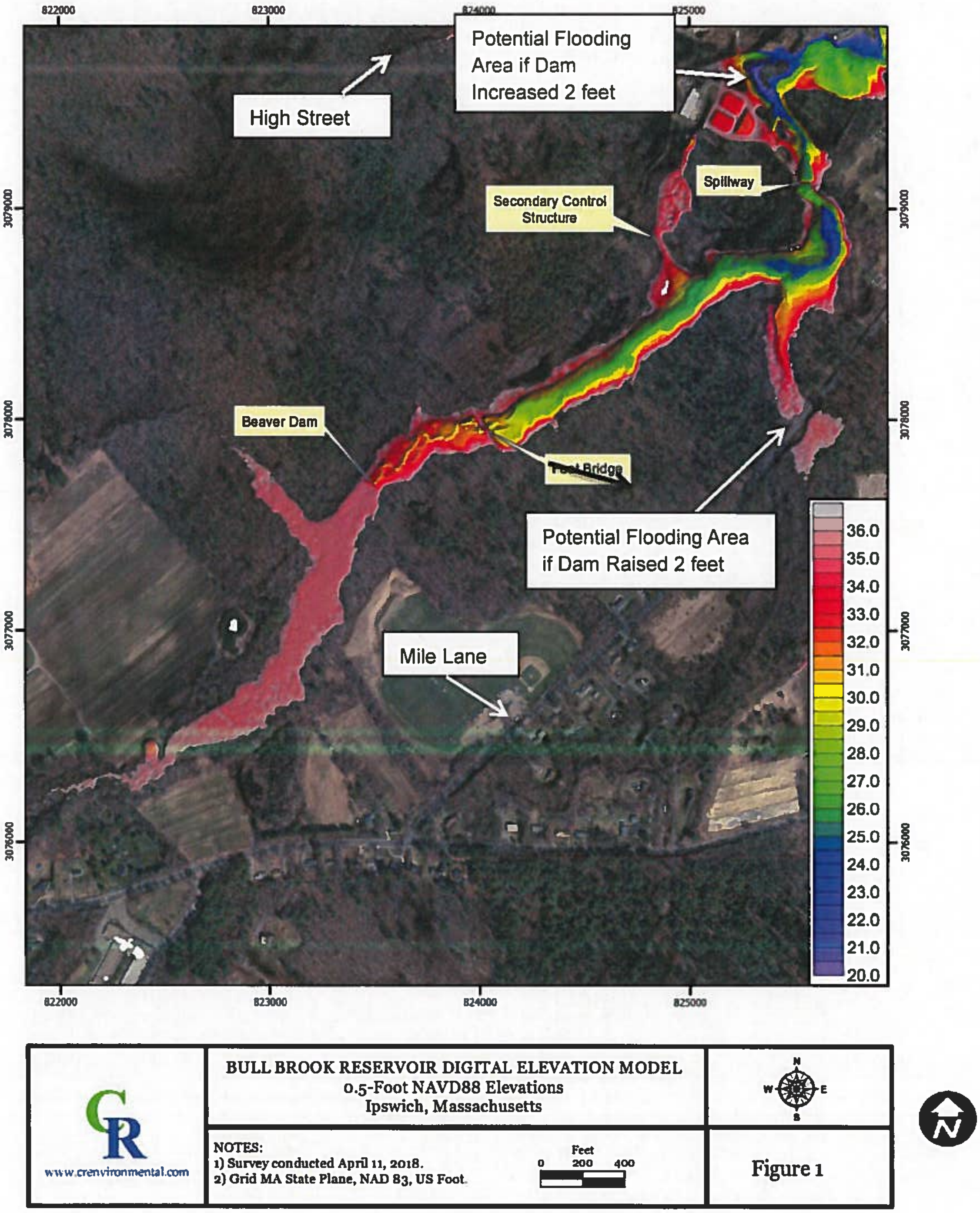


Figure 4-5. Bull Brook Reservoir

4.2.1.2 Technical Feasibility

Dow Brook Dam has recently been deemed unsafe by the Office of Dam Safety. Repair efforts are underway to make the dam safe. Provisions to raise the dam two feet are being incorporated into the repair work. The work to repair and raise the dam is scheduled to be complete by early 2019. However, raising the reservoir water level cannot be done until permits are obtained and impacts to surrounding wetlands and private property are addressed. Raising Bull Brook dam would require structural improvements to the dam. The first step would be to identify if raising the dam would be structurally feasible. Ipswich has the Bull Brook dam regularly inspected, however, a Phase II Investigation would be required. The Office of Dam Safety provides guidance on the components of a Phase II investigation including the following:

1. Hydraulic/Hydrologic Analysis
2. Dam Break Analysis
3. Structural stability analysis
4. Subsurface investigation
5. Soil and materials testing
6. Foundation exploration
7. Cost estimate and recommendations
8. Updated Detailed Phase 1 Investigation
9. Topographic survey, wetlands flagging/delineation, of sufficient detail to support not only the Phase II design effort, but sufficient for the future implementation of design phase.
10. Final report presented to the Office of Dam Safety including conceptual alternatives and conclusions.

4.2.1.3 Treatment Requirements / Staffing Needs

Increasing the storage volume at the reservoirs by raising the dam elevation should not change the treatment requirements or staffing needs. Increased storage would have immediate availability for drought resiliency.

4.2.1.4 Permitting

Raising the dams at each reservoir could inundate wetlands located adjacent to the reservoir. Wetlands that are disturbed would need to be reconstructed at a different location. Raising the dams could also impact local private property owners, requiring the Town to obtain easements. These improvements would require a Massachusetts Environmental Policy Act (MEPA) review and a wetlands permit. Raising the dam would also require a permit from the Office of Dam Safety. Projects for raising dams can take several years to permit if there is opposition from the stakeholders. However, the current situation at Dow Brook Dam may offer a more timely and cost-effective option.

4.2.1.5 Stake Holder Concerns

The stake holders for each of these reservoir sites would include the watershed associations and the private property owners located adjacent to the reservoirs. The reservoir storage would be increased by reducing the amount of water that goes over the spillway during the wetter months. The private property owners would, obviously, be concerned about flooding on their property.

4.2.1.6 Schedules

The estimated duration to design and construct the potential improvement to increase storage at the reservoir would be approximately 3 to 5 years, if there is no significant stakeholder opposition. This would allow time for the survey, dam inspections, and wetlands delineation, followed by design and construction. It is estimated that the permitting period would be 1 to 2 years but could most likely be done in parallel with the design.

4.2.1.7 Concept Level Opinion of Costs

The concept-level opinion of costs associated with raising the dams includes costs for a preliminary investigation, (such as topographic survey, borings, and wetlands delineation), design, permitting, bidding and construction. The Town of Ipswich has hired a contractor to replace the existing Dow Brook Reservoir Dam. The work would be the same to raise the dam because they are planning to make the dam sheeting high enough to increase the height of the dam by 2 feet. The low bid estimate for this work was $1,400,000. The cost of raising the Bull Brook dam was assumed to be one third of the cost to raise the Dow Brook Reservoir dam based on the difference in length. Based on this assumption, the estimated cost for the Bull Brook Reservoir Dam the work would be approximately $467,000. In addition to the prices for the dams there will likely be costs to construct embankments and reconstruct wetlands that may be inundated. A 40% allowance was included to account for these items. This brings the total cost $2.6 million.

4.2.1.8 Reservoir Expansion - Raise Existing Dams - Advantages and Disadvantages

Advantages

- Raising the dams would increase available storage.
- Raising the dams should not impact treatment requirements and staffing needs.

Disadvantages

- Raising the dams could inundate wetlands adjacent to the reservoir which would require a significant permitting effort and possibly reconstruction of wetlands.
- Possible flooding of private property
- Structural modifications would need to be made to Bull Brook Reservoir dam.
- Comparatively, a high cost per capacity increase.

4.2.2 Reservoir Expansion – Build Storage Tanks

Another option that was considered to increase storage volume at the reservoirs was to build raw water storage tanks on upland areas between the existing reservoirs.

4.2.2.1 Potential Capacity and Impacts

The Town of Ipswich owns land between the two reservoirs. Tanks could be constructed close to both reservoirs and the WTP. When the reservoirs are overtopping their spillways, a portion of the excess volume could be pumped to the water storage tanks for use during dryer periods. The volume of these tanks could be sized to meet the Town's demands. For example, the Firm Yield analysis done for raising the dams 2 feet indicated the storage volume would increase by 24 MG. This is estimated to increase the Firm Yield by 0.08 MGD. Therefore, if three, 10 MG storage tanks (30 MG) were constructed, it could potentially increase the Firm Yield by slightly more than 0.08 MGD.

4.2.2.2 Technical Feasibility

The storage tanks could be constructed on land that the Town owns between the two reservoirs. This land could be accessed by continuing the driveway at the water treatment plant. The first step would be to conduct a geotechnical investigation and topographic survey.

4.2.2.3 Treatment Requirements / Staffing Needs

Increased storage would have immediate availability for drought resiliency. Constructing new storage tanks adjacent to the existing reservoirs should not impact treatment or staffing needs. Additional staff may be necessary to support the new pump station and storage tanks.

4.2.2.4 Permitting

The permits required for constructing new water storage tanks adjacent to the existing reservoirs include: a MEPA review, a DEP permit to construct tanks and pumping facilities, and possibly a Water Management Act permit. The new water storage tank site could be located in upland areas outside of sensitive areas, which would minimize comments from the review processes.

4.2.2.5 Stake Holder Concerns

The stake holders for each of these reservoir sites would include the private property owners located adjacent to the reservoirs. The reservoir storage would be increased by reducing the amount of water that goes over the spillway during the wetter months. Reducing the amount or duration of spilling would be a concern to the watershed associations. Constructing new water storage tanks would limit impacts to private property owners because they would not increase the potential for flooding.

4.2.2.6 Schedules

The estimated duration to design and construct the potential improvement to increase storage at the reservoir would be approximately 3 to 5 years, if there is no significant stakeholder opposition. The duration for permitting the water storage tanks may be 1 to 2 years if they are constructed out of sensitive areas.

4.2.2.7 Concept Level Opinion of Costs

The opinion of costs for three, 10 MG storage tanks would be approximately $13.5 million, assuming that the tanks would be pre-stressed concrete, with approximate dimensions of 206 feet diameter x 40 feet water depth, and would be constructed with a spherical concrete dome roofs. The opinion of cost of site work, piping and a pump station is approximately $2 million, assuming three tanks, a 700 gpm pump station, 2,000 feet of 12 inch pipe, and clearing and grubbing approximately 5 acres. A 40% allowance was used to develop an opinion of cost for the topographic survey, borings, wetland delineation, design, permitting, bidding and construction. The concept level opinion of costs for expanding the reservoirs by adding storage tanks is approximately $22 million.

4.2.2.8 Reservoir Expansion- Build New Storage Tanks - Advantages and Disadvantages

Advantages

- Building storage tanks would increase available storage and the storage volume could be customized and built in stages.
- Tanks could be refilled periodically during the summer and fall, if significant rain events occur that would otherwise cause overtopping of the dams;
- Treatment requirements should not be impacted.
- Locating the tanks on adjacent uplands would limit permit requirements.

Disadvantages

- Operations would need to be adjusted seasonally and with weather events to optimize storage.
- The pump station associated with the storage tanks would require additional maintenance, power, and possible staffing.
- Comparatively, a high cost per capacity increase.
- Raw water quality degradation during the storage period would be a concern

4.2.3 Reservoir Expansion - Excavating around Reservoirs/Removing Sediment

The capacity of the reservoirs could potentially be increased by excavating around the reservoirs to expand the footprint of the reservoir or by removing sediment to increase the depth of the reservoir.

4.2.3.1 Potential Capacity and Impacts

Excavating material and removing sediment around the reservoir could potentially provide additional usable storage if the water elevation stays the same. AECOM assumed that the storage volume would increase by one gallon for every one gallon of soil excavated. To make this alternative comparable to the option to raise the dams two feet, we assumed that approximately 24 MG of soil would be excavated to increase the storage volume the same amount. We assumed that the majority of this volume would be removed from the peninsula in Bull Brook near Mile Lane. Based on the Firm Yield analysis this would also increase the Firm Yield by 0.08 MG.

4.2.3.2 Technical Feasibility

Sediment thickness was measured in each of the reservoirs by CR Environmental at the time of the bathymetric surveys. CR Environmental provided a memorandum summarizing the measurement procedures and results, which are summarized in the following paragraphs. In the Bull Brook Reservoir, the sediment was measured manually by driving a steel probe to refusal at evenly spaced locations along transects approximately 100 feet apart, with somewhat tighter spacing near the dams. Sediments were probed to refusal at 120 locations. Refusal depth data were digitally recorded for comparison with sounding data on the HYPACK acquisition computer. The sediment thickness at the 120 probe locations ranged from 0 to 5.4 feet averaging 1.8 feet. CR Environmental noted that probe penetration was generally greatest downstream, northeast of the footbridge. Probes were hand driven to refusal and a clean gray clay was frequently observed on the tip of the probe, suggesting penetration beneath the surface of pre-construction soils. Notes on the 1923 design drawings provided by the Town of Ipswich indicate that "All mud and vegetable matter to be removed to clean hard bottom inside of contour 31". This statement suggests that the clean hard bottom is likely the clean gray clay layer observed at probe refusal. Therefore, it would appear that overall there has not been significant sedimentation in Bull Brook Reservoir since it was constructed.

In the Dow Brook Reservoir the sediment was measured using a 10-kHz SyQwest Stratabox subbottom profiling (SBP) system. The SBP was interfaced to the RTK GPS and data were recorded along transects spaced 50 feet apart. Data were recorded in SEG-Y and ODC formats for post-processing. The sub-bottom acoustic system penetrated greater than 25-feet of lakebed deposits in deeper portions of the reservoir. The data suggests 1 to 2 feet of sediment accumulation after the reservoir was constructed.

Excavating sediment from each reservoir was considered as an option to increase the usable storage in the reservoir system. However, there does not appear to be a significant amount of sediment to be removed. It was also considered to excavate below the original bottom of the reservoir, however, the minimum usable water level in Bull Brook Reservoir is limited by the invert of the 36-inch diversion pipe. The minimum usable water level in Dow Brook Reservoir is limited by the invert of the low level intake. Based on the sediment survey conducted by CR Environmental, the sediment is not interfering with the flow of water at the diversion pipe. Therefore, sediment excavation will not increase usable storage.

4.2.3.3 Treatment Requirements / Staffing Needs

Increasing the storage volume at the reservoirs by excavating around the reservoirs would not change the treatment requirements or staffing needs. Increased storage would have immediate availability for drought resiliency, but plant capacity needs would need to be evaluated to asses if future demand needs can be met.

4.2.3.4 Permitting

Wetlands that are disturbed as part of the excavation process would need to be reconstructed at a different location. Excavating could also impact local private property owners requiring the Town to obtain easements. These improvements would likely require a Massachusetts Environmental Policy Act (MEPA) review and a wetlands permit. To the extent possible, excavating near wetlands and on private property would be avoided. Projects for excavating around reservoirs can take several years to permit if there is opposition from the stakeholders.

4.2.3.5 Stake Holder Concerns

The stake holders for each of these reservoir sites would include the private property owners located adjacent to the reservoirs. The reservoir storage would be increased by reducing the amount of water that goes over the spillway during the wetter months. Reducing the amount or duration of spilling would be a concern to the watershed associations. Private property should be able to be avoided.

4.2.3.6 Schedules

The estimated duration to design and construct the potential improvement to increase storage at the reservoir would be approximately 3 to 5 years if there is no significant stakeholder opposition. This would allow time for the survey, subsurface investigations, and wetlands delineation, followed by design and construction. It is estimated that the permitting period would be 1 to 2 years but could most likely we done in parallel with the design.

4.2.3.7 Concept Level Opinion of Costs

The concept-level opinion of costs associated with excavating around the perimeter of the reservoirs includes costs for preliminary investigation (such as, topographic survey, borings, and wetlands delineation), design, permitting, bidding and construction. Costs were developed to excavate the 24 MG of soil and haul and dispose of the material at a landfill. To estimate the excavation costs, we assumed that the material would be till. To estimate the hauling and disposal costs, we assumed a 20 mile round trip to a disposal site. The 24 MG of soil is approximately 136,700 cubic yards of material. We assumed the material would expand by approximately 15% after it is excavated. A 40% allowance was used to develop an opinion of cost for the topographic survey, borings, wetland delineation, design, permitting, bidding and construction. The concept level opinion of costs for expanding the reservoirs by excavating around them is approximately $6,700,000.

4.2.3.8 Reservoir Expansion- Removing Sediment/Excavating Around - Advantages and Disadvantages

Advantages

- Excavating in and around the reservoirs would increase available storage.
- Treatment requirements should not be impacted.

Disadvantages

- Excavating in and around the reservoirs could inundate wetlands adjacent to the reservoir which would require a significant permitting effort and possibly reconstruction of wetlands.
- Comparatively, a high cost per volume of storage added.

4.2.4 Reservoir Expansion - Building New Upstream Dams

Another option considered to increase reservoir storage was constructing upstream dams. This would involve constructing dams upstream in the Dow Brook and Bull Brooks, and expanding storage by inundating low lying areas. These smaller reservoirs would feed into the larger downstream reservoirs. The Town does own land around the reservoirs. However, inundating lands upstream of the reservoirs adjacent to the existing brooks would most likely impact wetlands and may impact private property owners. The area to be inundated would be substantial to store a significant amount of volume. For example, to store an additional 23 MG, assuming a depth of 10 feet, approximately 7.4 acres of land would need to be inundated. Wetlands that are inundated would have to be reconstructed in another location and easements would have to be purchased. Obtaining permits for wetland inundation and replication could be difficult and time consuming, therefore, building new upstream dams as not considered further.

4.2.5 Reservoir Expansion- Building Upstream Dams- Advantages and Disadvantages

Advantages

- Building new upstream dams would increase available storage.
- Treatment requirements would not be impacted.

Disadvantages

- Building upstream dams could inundate wetlands adjacent to the reservoir which would require a significant permitting effort and possibly reconstruction of wetlands.
- Private property owners could be impacted by building new upstream dams.
- Obtaining permits for wetland inundation and replication could be difficult and time consuming, therefore, building new upstream dams as not considered further.

4.3 Desalination

Desalination is a process for removing salt and minerals from seawater, or from brackish surface or groundwater, to obtain fresh water. Desalination could increase the total amount of usable water and provide a reliable water supply. This option would entail construction of water-supply wells, and constructing a new desalination plant, using either reverse osmosis (RO) or nanofiltration (NF) membranes. AECOM's screening-level evaluation considered location, raw water source, discharge of brine, access and proximity to the existing water distribution system, and treatment processes. We should emphasize that AECOM considered only brackish groundwater as the source water, and not the ocean..

The Town has considered desalination in the past, but dismissed it due to its high operation and maintenance cost. Current desalination technology is a pressure driven (pumped) process, and the cost of energy to drive these pumps has historically been a major financial hurdle. From an environmental perspective, brine waste disposal has also presented challenges.

As fresh water scarcity has increased over the last several years, desalination technologists have been focusing on creating more economical and sustainable processes. Advancements in membrane science have resulted in a movement away from cellulose acetate RO membranes to more durable polymeric RO membranes, offering a longer membrane life. Energy recovery devices are frequently incorporated into the membrane systems to reduce the overall power consumption. Proprietary cleaning agents and anti-scalants have been developed to reduce the cleaning cycles and allow for higher system recoveries (and thus less brine).

Figure 4-6. Existing WWTP Location and Outfall

4.3.1 Potential Capacity

The capacity of the desalination plant would be dependent on the capacity of the groundwater source, which is currently unknown. The Town would need to undertake a combination of test-well drilling, geophysical surveys and related studies to identify the capacity of the groundwater source. Groundwater-quality testing would be an additional and critical component of the groundwater investigation, since salinity is a key consideration. A new desalination plant would be sized to treat as much water as available. Further investigation on groundwater capacity would be required to decide if the desalination plant could be used to supplement a portion of the water supply or to replace all existing supplies and be the sole source of water for the Town.

4.3.2 Technical Feasibility

The Town of Ipswich owns a parcel of land near the coast where the Town's wastewater treatment plant (WWTP) is currently located. This site appears to have sufficient space for a new water treatment plant. To provide raw water for the treatment-plant site, groundwater wells would be constructed. Again, we did not consider the ocean as a source of water. If a significant source of groundwater is identified, we would expect a consistent, brackish water supply, which is far less costly to treat than ocean water. Brackish water would likely contain far lower salinity than ocean water. Sea water salinity typically measures between 30,000 and 35,000 mg/L, and the pressure through the membrane needed to remove the high salinity is on the order of 800-1000 psi (the higher the salinity, the higher the RO operating pressure). Seawater reverse osmosis (SWRO) would require a pre-treatment system to protect the RO membranes from premature fouling, and a high volume of brine waste would be generated. In contrast, the salinity of brackish water is typically below 5,000 mg/L. The lower salinity would reduce the brackish water reverse osmosis (BWRO) feed pump pressure to 150-300 psi. Brine volume and groundwater pre-treatment requirements would be reduced. In turn, this would reduce the size, construction costs, and operating cost of the new desalination plant compared to a SWRO desalination plant. For these reasons, BWRO is far more feasible than SWRO in Ipswich. Therefore, we removed SWRO from further consideration.

The Town owns property adjacent to the salt marsh east of the WWTP. Subsurface investigations and pumping tests would need to be conducted to assess the viability and capacity of potential well sites. As noted, the desalination process would produce, as a byproduct, high-salinity brine that would need to be discharged to the ocean. Constructing an outfall to discharge into the Greenwood Creek would be challenging because this is an environmentally sensitive area. In addition, because of the high salt levels, care would need to be taken to dilute the brine before discharging it to Greenwood Creek. The Ipswich WWTP currently discharges its treated effluent into Greenwood Creek. It may be possible to combine the brine with the discharge from the WWTP. Combining the two flows would dilute the brine and produce a discharge similar to or lower than sea water. Therefore, a new outfall would not be needed. According to the Ipswich WWTP Emergency Response Plan: Two-Dimensional Water Quality Modeling, Town of Ipswich, Massachusetts (prepared by AECOM for the Ipswich Utilities Department in May 2015), the WWTP discharge to Greenwood Creek is 1.5 cfs (1.0 MGD) on an average annual basis, and 5.6 cfs (3.6 MGD) for a peak day flow.

The treated water from the desalination plant would need to be conveyed to the existing water distribution system. This water would need to be disinfected, and then stabilized using post-treatment chemicals such that pH, alkalinity, and hardness would closely match that of the existing distribution system water quality. The Town has an existing water storage tank located approximately 1,200 feet south of the WWTP. The treated water from the desalination plant could be pumped to the existing water storage tank, limiting costs for transmission mains.

4.3.3 Treatment Requirements/Staffing Needs

Pilot studies would need to be conducted to evaluate potential treatment options, based on the actual salinity of the water to be treated. Very low salinity water (< 1,500 mg/L) could allow the use of nanofiltration, sometimes referred to as low pressure RO, the most economical form of membrane desalination. The new BWRO plant would require a full time staff to maintain and operate the facility. However, if sufficient capacity is available, this plant could become the sole source of water for the Town, potentially eliminating the other sources, and requiring no net increase in staffing needs.

4.3.4 Permitting

Constructing a new desalination plant would require a New Source Approval permit for the supply wells, MEPA review, a DEP Permit to Construct Wells/Pumping Facilities, and a DEP Permit to Construct a Water Treatment Plant Facility. A mandatory Environmental Impact Report (EIR) is required for any new withdrawal or expansion of 2.5 MGD for surface water, or 1.5 MGD for groundwater. Even if a mandatory EIR is not triggered, it is likely that one will be required after review of the ENF. In addition, wetlands permits may also be required. There may also be additional permitting associated with the construction of a transmission main. However, if the project could be designed and constructed without a new outfall, permitting could be less complicated. It is not clear whether permitting would be required under the WMA program.

4.3.5 Stake Holder Concerns

The stake holders could include the Parker and Ipswich River Watershed associations and other environmental groups. This alternative could be well received by these stakeholders because it could reduce the amount of water removed from wells and reservoirs in these watersheds. This new source would decrease the Town's dependence on sources in the Parker and Ipswich River watersheds. It may be possible that the treated water could be sold to surrounding communities, if there is excess supply. This alternative would also impact the Wastewater Department due to strict NPDES permitting requirements governing the wastewater effluent, as well as the Division of Marine Fisheries due to potential impacts on local shell-fishing operations.

4.3.6 Schedules

It is estimated that the new BWRO plant could be permitted, pilot tested, designed and constructed in 5 to 7 years.

4.3.7 Concept Level Opinion of Costs

The concept level opinion of costs associated with a BWRO plant includes preliminary investigation expenses (such as survey and wetlands delineation, well water pumping and water quality tests, pilot testing of the water treatment process), design, permitting and construction. Given the uncertainty in salinity, specific to Ipswich, we cannot estimate project costs at this time. However, for reference AECOM has recently designed a 3 MGD BWRO plant at a cost of about $18,000,000. A 40% allowance should be added for including the cost of topographic survey, borings, wetland delineation, design, permitting, bidding and construction. The concept level opinion of cost for the desalination plant is approximately $25,000,000. However, as noted above, the scope of the project would have to be further refined to better estimate project costs.

4.3.8 Desalination Advantages and Disadvantages

Advantages

- The property for the desalination plant is already owned by the Town.
- Could replace the existing WTP as long as there is sufficient supply available.
- Reduces the amount of water removed from the Parker River and Ipswich River watersheds.
- Could improve drought resiliency.
- The existing WWTP outfall could be utilized
- The distance to connect to the Town's water system infrastructure is relatively close

Disadvantages

- Significant permitting requirements.
- The potential capacity is unknown without further investigation.
- A new water treatment plant would need to be constructed
- Operating costs could be excessive, depending on the salinity.
- Additional staffing requirements. However, if the existing water treatment plant could be removed from service this would not be an issue.

4.4 Wastewater Reuse

Over the past several years, wastewater reuse has increasingly been considered as an option by communities with severe water shortages. In response, the USEPA has published Guidelines for Water Reuse (2012) to provide a framework for technical and regulatory standards related to this practice. These guidelines address the following major variations of wastewater reuse:

- Potable Reuse (PR): the intentional use of reclaimed wastewater for drinking water supply
- Direct Potable Reuse (DPR): the introduction of reclaimed water into a drinking water treatment plant
- Indirect Potable Reuse (IPR): Supplementing a drinking water source (either a surface water or an aquifer) with treated reclaimed water.

Currently, reuse practices in the US are dominated by IPR programs rather than DPR programs. Long term severe droughts in Texas have spurred the implementation of a handful of DPR projects (Wichita Falls most notably), but the cost, regulatory permitting, and barriers created by public perception significantly favor IPR instead. Further, according to the USEPA document entitled 2017 Potable Reuse Compendium, no states have formal regulations governing DPR. Rather, DPR facilities are regulated on a case-by-case basis. For Ipswich, the feasibility of reuse is limited to IPR. The Commonwealth of Massachusetts does have policies to address IPR (314 Code of Massachusetts Regulations 20.00 – Reclaimed Water Permit Program).

The Town's WWTP currently discharges to the Greenwood Creek. An IPR alternative would include reclaiming and treating that discharge and reusing it to reduce the impacts to the Town's source water supply during the high use period of summer. A treatment plant and a transmission main would need to be constructed to convey the treated water to the reuse site. Potentially, the water could be used as a dedicated irrigation supply, or it could be pumped to a location for recharging groundwater upstream of the reservoirs. This alternative could help minimize demands for irrigation water in the summer months and help replenish the reservoir watershed during drought conditions. It would not, however, provide immediate relief for the demand for drinking water.

4.4.1 Potential Capacity

On an average-annual-flow day, the WWTP discharge is 1.5 cfs (1.0 MGD). This discharge would require additional tertiary treatment before it could be reused. If it is assumed that the full 1.0 MGD is treated, and allowing for losses in treatment from backwashing, brine generation, or solids removal, a final water capacity of about 0.9 mgd could be expected.

4.4.2 Technical Feasibility/Treatment Requirements/Staffing Needs

For the purposes of this discussion, it is assumed that the most feasible reuse application would be in the form of discharge to a Zone II well head or for recharge to an aquifer. Preliminarily, a Class A water quality standard would need to be met. This requires (among other things) total suspended solids (TSS) < 5 mg/L fecal coliform of no detectable concentrations over a continued 7 days of sampling, and a BOD of < 10 mg/L. In contrast, the Ipswich WWTP NPDES permit requires TSS and BOD < 30 mg/L (average monthly) and allows for fecal coliforms of 14 cfu/100 mL. Using the permit limits as representative of the water quality to be treated and reused, it is likely that to meet the Class A standards, some additional treatment will be required.

With this in mind, a review of the 2017 Potable Reuse Compendium shows that IPR projects, where the treated water is discharged back to surface water (or watershed), have used the following unit processes in order to obtain regulatory approval;

Membrane microfiltration__> Reverse osmosis _> advanced oxidation (ozone or UV/peroxide).

Many variations to this unit process arrangement could be considered, but at this time, it is safe to assume that a fairly complex treatment process could be required, as well as a pump station and transmission main. Although it is assumed that the IPR process would only activate during the summer months, additional treatment plant staff would be needed

4.4.3 Permitting

The MADEP would need to approve and issue a permit for Reclaimed Water Discharge. The application for permit must include an Engineering Report, a Reuse Management Plan, and a pilot study report demonstrating that the treatment scheme will meet the effluent requirements. A Groundwater Discharge Permit would also be required.

Implementing wastewater reuse would require a MEPA review process and a DEP Permit to Construct Treatment Facilities. Permitting associated with the construction of a transmission main is likely. If this option was selected, the project would need to be better defined so that DEP could provide input on any additional permitting requirements. DEP may also have input on the level of treatment which could impact the treatment process and costs.

4.4.4 Stake Holder Concerns

The stake holders for this new supply include the Town and the potential users for this reused water. Potential customers for this water would need to be identified. Reusing wastewater may not be received favorably by the public or the stake holders. This has been the obstacle on numerous other DPR and IPR programs around the country. The term "toilet-to-tap" is a common phrase that the public is introduced to when reuse is under discussion. Although there could be a potential positive impact to the watershed by importing water that otherwise goes to the ocean, the public perception issue would be major hurdle.

4.4.5 Schedules

It is estimated that the new plant could be permitted, pilot tested, designed and constructed in 4 to 7 years.

4.4.6 Concept Level Opinion of Costs

The concept level opinion of costs associated with wastewater reuse includes preliminary investigation expenses, (such as survey and wetlands delineation, pilot testing of the additional waste water treatment process), design, permitting and construction. The scope of the options would have to be further refined to estimate costs. The reused water would need to be pumped to a location within the reservoir watershed or to a potential dedicated irrigation customer (such as a golf course or farm). This would require the construction of a new transmission main. Since the exact location of the discharge is not known it was assumed a transmission main 4 miles long would be needed. The opinion of costs for construction of a transmission main is $1 million per 1 mile of main, in 2018 dollars, or $4M. The concept level opinion of costs for this wastewater reuse is difficult to estimate at this time. As a rough metric, the 2017 Potable Reuse Compendium provided ranges of construction costs based on operational IPR facilities, averaging about $7/1000 gallons treated. Assuming a 0.9 mgd capacity, this works out to $6M, but to then account for topographic survey, borings, wetland delineation, design, permitting, bidding and construction, adding another 40%, the capital cost could be approximately $8.5M. Thus, the concept level opinion of costs for wastewater reuse is approximately $12,500,000.

4.4.7 Advantages and Disadvantages

Advantages

- WWTP discharge would be used to recharge the groundwater or watershed basin.

Disadvantages

- A surface water or groundwater discharge permit would likely be required, along with numerous other permits required by MADEP's Reclaimed Water Program.
- Treatment processes, pumping equipment and transmission main would be idle during winter and spring when the demand is low, and the reservoirs are full;
- Emerging contaminants now found in wastewater would be recharged into the Town's source water;
- The WWTP discharge would need to be treated to a Class A standard requiring an additional treatment process be built at the WWTP.
- Reusing wastewater may not be received favorably by the public or the stake holders.

4.5 Interconnections with Surrounding Communities

This alternative includes constructing interconnections or utilizing existing interconnections with the surrounding communities. The Town currently has interconnections with Rowley and Hamilton. However, these interconnections are not currently utilized and there are no existing intermunicipal agreements. The Hamilton interconnection was last used in the 1980's. This alternative is not expected to increase the water supply during drought conditions, since neighboring communities would likely be experiencing similar conditions. However, an interconnection could be useful in the event of an emergency or while conducting maintenance on existing facilities. Considerations were also made for interconnecting with a larger water supplier such as the MWRA or the Salem Beverly Water Supply Board. Unfortunately, neither of these potential sources extend close enough to Ipswich for a connection to be made without construction of a significant length of water main.

4.5.1 Potential Capacity/Technical Feasibility/Treatment Requirements/Staffing Needs

The communities being connected to would have to be contacted to estimate the volume of water they could provide to Ipswich. This would depend on available water pressures. Water pressures and water quality for surrounding communities would need to be evaluated. The water quality would need to be analyzed to determine if there are any concerns about differing water qualities causing pipe corrosion. Intermunicipal agreements would need to be created with the communities to detail terms and conditions. Staffing would only be required when the connections were being activated and to monitor them once they are brought online.

4.5.2 Permitting

In locations where interconnections already exist, minimal to no permitting would be required. Constructing and interconnection would have minimal permit requirements depending on where the connection is made. At a minimum it would require a DEP Permit for Modifying Water Distribution System. However, if the connection is made in a wetland area the permitting requirements would become more substantial. It is not anticipated that there would be issues with WMA permitting. The communities would need to have sufficient permit or registration volumes.

4.5.3 Stake Holder Concerns

The stake holders for this alternative would be the Town of Ipswich and the communities with which Ipswich abut. Potentially if that community could provide emergency water to Ipswich, then Ipswich could provide that community with water for an emergency. Water quality would be a concern for both communities. The water quality would need to be evaluated to make sure it is consistent.

4.5.4 Schedules

It is anticipated that it would take approximately 2 years for evaluation, design and construction of an interconnection.

4.5.5 Concept Level Opinion of Costs

The concept level opinion of costs will vary depending on if existing interconnections can be used or if new ones need to be built. The location of the interconnection would need be further refined to estimate costs. In addition, costs could include a study of water quality, chemical addition and pumping requirements.

4.5.6 Advantages and Disadvantages

Advantages

- Provides water supply in the event of an emergency.

Disadvantages

- Does not increase drought resiliency since surrounding communities will likely be in a drought at the same time.
- Water quality will need to be reviewed to check that it is consistent and identify adjustments that may need to be made.

4.6 Summary and Recommendations

The eight potential screening-level options considered for increasing the water supply to the Town of Ipswich were evaluated above. For each option, the potential increase in capacity, technical feasibility, treatment requirements, staffing needs, permitting requirements, stakeholder concerns, project schedule and concept level opinion of costs were evaluated. The table below presents a summary of these eight water supply alternatives.

Table 4-4. Summary of Screening-Level Water Supply Options

Potential New or Additional Capacity (MGD)	Technical Feasibility	Treatment Requirements	Staffing Needs	Permitting	Schedule	Concept Level Opinion of Costs (1)
New or Replacement Groundwater Supplies						
New Lynch Well Site (2)						
0.73	Construction of wells and pumping facilities; approx. 0.5 acres of land acquisition to meet Zone 1 requirements	Onsite treatment for corrosion control, chlorination, and fluoride addition	No change	DEP New Source Approval; ENF; WMA Permit Amendment; Permit to Construct Wells and Pumping Facilities	Operational within 2 years	$2,960,000 (does not include cost of land acquisition)
Browns Well Replacement with Greensand Filtration Plant						
0.29	Construction of replacement well and modifications to existing pumping facility; construction of greensand filtration plant	Greensand filtration plant; onsite treatment for manganese, corrosion control, chlorination, and fluoride control	Potential additional staff needed	DEP Replacement Well Approval; Permit to Construct Wells and Pumping Facilities; additional permitting for greensand filtration plant	Operational within 4 years	$5,125,000
Browns Well Replacement with Transmission Main to WTP						
0.29	Construction of replacement well and modifications to existing pumping facility; construction transmission main to existing WTP	treatment for manganese, corrosion control, chlorination, and fluoride control at existing WTP	Potential additional staff needed	DEP Replacement Well Approval; Permit to Construct Wells and Pumping Facilities; additional permitting for transmission main	Operational within 4 years	$1,600,000 (Assumes no modifications required at WTP)
Reservoir Expansion						
Raising Existing Reservoir Levels						
0.08	Structural assessment of existing dams; raise each dam by two feet	No change	No change	MEPA Review; wetlands permit, Office of Dam Safety permit	Operational within 3-5 years (includes 1-2 years of permitting)	$1,800,000
Building New Raw Water Storage Tanks						
0.08	Construction of three 10 MG storage tanks and a new pump station	No change	Potential additional staff needed	MEPA Review; DEP Permit to Construct Wells/Pumping Facilities; possibly a WMA Permit	Operational within 3-5 years (includes 1-2 years of permitting)	$22,000,000

Potential New or Additional Capacity (MGD)	Technical Feasibility	Treatment Requirements	Staffing Needs	Permitting	Schedule	Concept Level Opinion of Costs (1)
Excavating Around Reservoirs						
0.08	Excavate around the reservoirs to expand footprint	No change	No change	MEPA Review; wetlands permit	Operational within 3-5 years (includes 1-2 years of permitting)	$6,700,000
Desalination						
1 - 3	Construct a new desalination water treatment plant, intake wells, and transmission main	New desalination plant with reverse osmosis membrane technology	Potential additional staff needed	DEP New Source Approval; MEPA Review; Mandatory EIR; Permit to Construct Wells and Pumping Facilities; wetlands permit	Operational within 5-7 years	$25,000,000
Wastewater Reuse						
0.9 (3)	Construct new treatment process, pump station, and transmission main	Additional tertiary treatment at WWTP to meet Class A standard	Potential additional staff needed	MEPA Review; DEP Permit to Construct Wells and Pumping Facilities	Operational within 4-7 years	$12,500,000
Interconnections with Surrounding Communities						
No Additional Capacity	Contact neighboring communities and develop intermunicipal agreements; evaluate compatibility of water pressure and quality	Varies based on water quality analysis	No change	DEP Permit for Modifying Water Distribution System; possible wetlands permit	Operational within 3 years	Varies

Notes:

1) ENR Construction Cost Index, July 2018 dollars. Includes permitting, design, and construction. Long-term operation and maintenance costs are not included.

2) In February 2018, AECOM began the process of testing the Lynch Well Site under New Source Approval. Refer to AECOM's Test Well Investigation Report dated January 17, 2017, for additional information.

3) The volume of water produced by the wastewater reuse alternative cannot be directly attributed to Firm Yield because the volume would be discharged upstream of the reservoirs into the watershed and only a portion would be directly available for Firm Yield. However, the cost was included for comparison purposes.

To aid in the selection of the three most-advantageous water-supply options, AECOM prepared two tables. In Table 4-5, the alternatives were compared using an alternative comparison matrix. In Table 4-6, the potential increase in water-supply capacity, the concept-level opinion of costs, and the dollar-per-gallon of additional capacity are presented for each alternative.

The alternative comparison matrix considers the following criteria:

1. Potential increase in capacity,
2. Allows or helps the Town to meet future needs,
3. Concept opinion of construction cost,
4. Staffing,
5. Permitting,
6. Provides drinking water without requiring additional treatment; and
7. Time to implement.

The New Well Fields alternatives were grouped together for this evaluation. Likewise, the Reservoir Expansion alternatives were grouped. Each of the alternative categories was given a score of 1 to 5, 5 being the most advantageous. For example, in the category of "Increases Capacity", Desalination was scored a "5" because the desalination plant would be supplied by groundwater, which may not be impacted by drought, and could meet the entire Town demand. The Interconnections alternative was given a "1" because the communities that would have interconnections would also be impacted by drought and would not likely be able to provide additional supply.

Table 4-5. Alternative Comparison Matrix

	Options				
	New Well Fields	**Reservoir Expansion**	**BWRO Desalination**	**Wastewater Reuse**	**Inter-connections**
Increases Capacity	4	2	5	2	1
Allows or Helps Town to Meet Future Needs	4	2	5	2	1
Concept Level Opinion of Construction Cost	4	1	2	3	4
Staffing	4	5	2	2	4
Permitting	4	3	3	2	4
Provides Drinking Water without Requiring Additional Treatment	3	4	2	1	3
Time to Implement	5	4	3	3	4
Total	**28**	**21**	**22**	**15**	**21**

The total score for each alternative was tabulated with the highest score being the most advantageous. The New Well Fields alternative received the highest score of 28, Desalination received the second highest score of 22, followed by Reservoir Expansion with a score of 21. Interconnections received a score of 21 because it will not increase capacity during drought. However, this alternative should be implemented to reduce system vulnerability. Wastewater reuse received the lowest score because there would not be a direct increase in capacity, it would require additional staffing, and it would require a significant permitting effort.

Table 4-6 presents for each alternative: 1) the increase in potential capacity, 2) the concept level opinion of costs and 3) the dollar per gallon of additional yield. The alternatives are listed in order of the lowest dollar per gallon of additional yield to the highest dollar per gallon of additional yield.

Table 4-6. Water Supply Alternative Firm Yield Increase

Alternative	Potential Capacity Increase	Opinion of Cost (millions)	Dollar per Gallon of Additional Capacity
Lynch Well Site	0.73 MGD	$ 2.96	$ 4.10
Browns Well Replacement with Transmission Main to WTP	0.29 MGD	$1.6	$5.00
BWRO Desalination	1 -3 MGD	$ 25	$ 8.30- $24.90
Wastewater Reuse	0.9 MGD	$12.5	$13.90
Browns Well Replacement with Greensand Filtration	0.29 MGD	$ 5.1	$18.20
Reservoir Expansion - Raising Existing Dams	0.08 MGD	$2.6	$32.50
Reservoir Expansion - Excavating Around Reservoirs	0.08 MGD	$6.7	$83.75
Reservoir Expansion- Building Storage Tanks	>0.08 MGD	$ 22	$ 275
Reservoir Expansion - Building New Upstream Dams	Likely difficult to permit	-	-
Interconnections with Surrounding Communities	Would not increase Firm Yield.	-	-

As noted in previous sections, the Town's current available water-supply capacity can be restricted to as low as 0.96 MGD during drought conditions, which is not sufficient to meet the current demands. To meet the projected future demand, the Town will need to maintain its existing sources and increase its water supply by approximately 0.43 MGD. Whether the alternative can meet existing and future demands is used as a basis for comparison.

The alternative with the lowest cost-per-gallon of increase in capacity is the Lynch well site, with an estimated opinion of cost of $4.10 per gallon of increase. This alternative could increase the water-supply capacity by up to 0.73 MGD. This alternative would allow the Town to meet the future demand in 2040. The Lynch Well Site is located in the Parker River Basin. To meet the existing demands the Town's authorized withdrawals under the WMA in the Parker River Basin would not need to be increased. However, to meet future demands, the WMA withdrawal volume for the Parker River Basin would need to be increased by 0.21 MGD.

The alternative with the second lowest cost-per-gallon of increase in capacity is Brown's Well Replacement with Transmission Main to the WTP, with an estimated opinion of cost of $5.80 per gallon of increased capacity. This alternative is estimated to increase the water-supply capacity by approximately 0.28 MGD. The increase of 0.28 MGD would still fall short of meeting the demands in 2040. However, this alternative would provide Ipswich time to assess actual demand increase and other opportunities to optimize the use of other water supply sources. The Browns well is located in the Parker River Basin. To meet the existing demands, the Town's authorized withdrawals under the WMA in the Parker River Basin would not need to be increased. Though, to meet future demands, the WMA withdrawal volume for the Parker River Basin would need to be increased by 0.21 MGD.

The alternative with the third lowest cost per gallon of increase in capacity is brackish water desalination with an estimated opinion of cost ranging from $8.30 to $24.90 per gallon of increased capacity depending on the capacity of the plant. We have assumed that this alternative could increase the water-supply capacity from 1.0 to 3.0 MGD. This alternative would allow the Town to meet current and future demand in 2040. The desalination alternative would use brackish groundwater wells. It is not clear whether DEP would consider these withdrawals to be in one of the major river basins. Therefore, we do not know how the DEP WMA program would view the desalination option.

Comparing the alternatives based on cost per gallon of increase in capacity and the alternative comparison matrix, AECOM found that the New Well Fields and Desalination were the most advantageous.

The Town completed a 15-day pumping test at the Lynch well in August 2018, and submitted the New Source Final report to DEP in December 2018. The Lynch Well Site is awaiting DEP approval for new source of water supply of up to 0.73 MGD in capacity

Below is a summary of each alternative that was evaluated

New Well Field(s)

The New Well Fields alternative received the two highest scores in the alternative comparison matrix and had the lowest cost per gallon of additional water-supply capacity. It should be noted that more cost detail is available for the new and replacement well options because AECOM has been working with the Town on these issues over the past several years. In terms of dollars per gallon of additional capacity, the Lynch Well Site has a cost of $4.10 per gallon; Browns Well, with a transmission main has a cost of $5.80 per gallon; and Browns Well with a greensand filtration plant has a cost of $18.30. The Lynch Well Site would provide sufficient capacity to meet current and future demands. Browns Well would meet current demands and provide flexibility but would not meet the full 2040 estimated ADD. As stated above, the Lynch Well Site is awaiting DEP approval. . The Brown's well alternatives are presented in further detail in Section 5 of this report.

Reservoir Expansion

Increasing the storage volume at the reservoirs received the third highest score in the alternative comparison matrix. This alternative included four options for expanding the reservoirs: Raising Existing Dams, Building Storage Tanks, Excavating Around the Reservoirs, and Building New Upstream Dams. Building new upstream dams has been removed from consideration because of the impacts to wetlands, which would require a lengthy permitting process. Raising the Dow Brook and Bull Brook Reservoir dams is estimated to increase the storage volume at the reservoirs by approximately 24 MG which would increase the Firm Yield by approximately .08 MGD. Raising the dams had the third highest estimated opinion of cost of $32.5 per gallon of additional yield. Building additional storage tanks had the highest estimated opinion of cost at $275 per gallon of additional capacity. Therefore, it was not recommended for further evaluation. Excavating around the reservoirs could also increase the Firm Yield by approximately .08 MGD and had a cost of $83.75 per gallon of additional capacity. AECOM does not recommend that Raising the Existing Dams and Excavation Around the Reservoirs be further evaluated.

Brackish Water Desalination

Brackish water RO desalination received the second highest score on the alternative comparison matrix. AECOM estimated a cost of $8.30 per gallon of additional capacity, assuming a supply of 3 MGD can be found. The new BWRO plant could be constructed on land already owned by the Town. This alternative would optimize the use of existing infrastructure by discharging brine to the existing WWTP discharge outfall, and making use of the existing water storage tank located nearby. We have assumed that the groundwater will be brackish in quality. A program of test-well drilling, geophysical studies, water-quality testing and other studies will be needed to estimate the quantity and quality of the water available. If the wells can provide enough water to meet the Town's current and future demands, the Town could consider abandoning some or all of its existing sources of supply. This alternative has many unknowns at this time, the greatest being well capacity and degree of salinity. Constructing a new brackish water desalination plant is recommended for further evaluation.

Wastewater Reuse

Wastewater reuse received the lowest score on the alternative comparison matrix because it does not directly increase capacity and therefore would not help the Town meet current or future needs. The reused wastewater could only be discharged when the ground is not frozen and would require additional staffing, and could potentially be difficult to permit. The volume of water produced by the wastewater reuse alternative cannot be confidently estimated because the water would be discharged upstream of the reservoirs into the watershed, where only a portion would recharge the reservoirs. Despite these unknowns, the cost was estimated for comparison purposes. Assuming that wastewater reuse could provide an additional 0.9 MGD in capacity, we estimated a cost of $13.90 per gallon of additional capacity. Although it could potentially increase the volume of water stored in the reservoirs in the warmer months, which are the high demand times, it does not increase the overall supply. Further investigation would be required to gauge interest from potential customers and the community if the Town wishes to pursue the wastewater reuse option. While wastewater reuse could improve streamflow and increase supply in the summer, reuse has a number of complications and drawbacks. For example, significant questions about the Town's drinking water-quality could be a major concern to both DEP and the community. The "toilet-to-tap" argument is likely to be raised by the community, especially given concerns about emerging contaminants. This alternative is not recommended for further evaluation.

Interconnections

Interconnections received the second lowest score on the alterative comparison matrix because it would not increase yield or help the Town to meet future needs. This is because the surrounding communities are likely to be in drought conditions at the same time as Ipswich. It would be beneficial to have these connections for emergencies, for example, in the case of failure at the WTP or contamination of wells. Connections with larger water suppliers such as MWRA or Salem Beverly would require construction of a significant length of water transmission main. In addition, the connections to Salem Beverly would require connections through multiple Towns, causing concerns with water quality and hydraulic pressure. Creating interconnections with surrounding communities is not recommended for further investigation.

Three Options for Further Consideration

AECOM met with the Town in late November 2018 to present the results of the screening-level evaluation of potential water-supply alternatives. . After due consideration and thought, we reached a consensus on the three most favorable options for further investigation:

1. New Lynch Well Site
2. Browns Replacement Well
    a. Browns Replacement Well with Transmission Main to the WTP, or
    b. Browns Replacement Well with a new Greensand Filtration Plant
3. Desalination (brackish groundwater).

As mentioned above testing and permitting of the Lynch Well Site is already underway. The Lynch Well, Browns Well and desalination alternatives are discussed below in Section 5 in more detail.

5 Three Recommended New Water Supplies or Expansion Alternatives

As stated above, the Town and AECOM selected the following three alternatives for further consideration:

1. New Lynch Well Site
2. Browns Replacement Well
    a. Browns Replacement Well with Transmission Main to the WTP, or
    b. Browns Replacement Well with a new Greensand Filtration Plant
3. Desalination (brackish groundwater).

Figure 5-1 presents a location plan for each of the alternatives and the sections below provide the additional information on each of the alternatives.

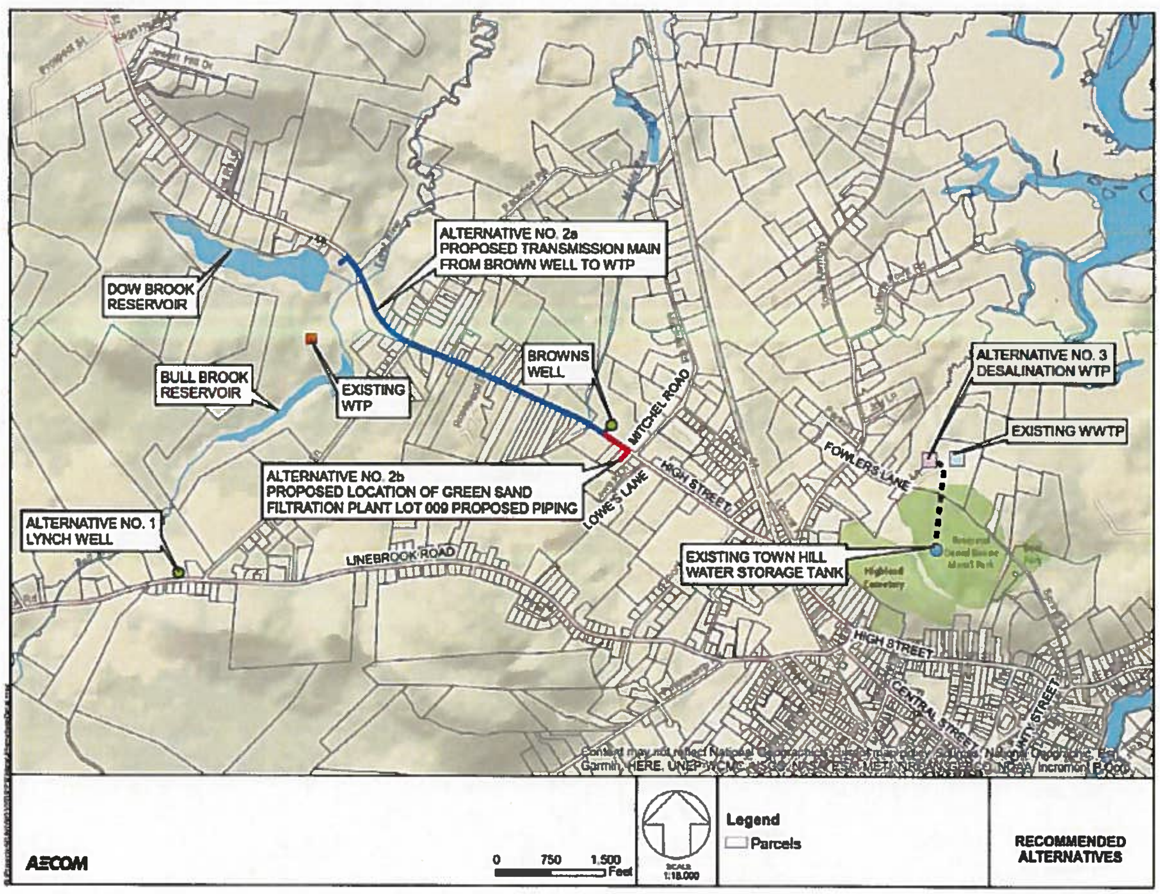


Figure 5-1. Three Recommended New Water Supplies or Expansion Alternatives

5.1 Alternative 1: Development of the Lynch Well Site

Alternative 1 would involve the development of the Lynch Well Site as a new source of groundwater supply. The Lynch Site was subjected to a 15-day continuous pumping test in August 2018 under the DEP New Source Approval process. Based on the pumping test, the Calculated Approvable Yield for a future well field of four gravel-packed wells is 510 gallons per minute (gpm), or 0.73 MGD

Water-quality testing conducted during the pumping test indicates that the water meets primary and secondary Maximum Contaminant Levels (MCLs and SMCLs) established by the US Environmental Protection Agency (EPA) and enforced by the Massachusetts DEP. Low levels of coliform bacteria were identified. To meet the requirements of the EPA Ground Water Rule and achieve 4-log (99.99%) inactivation of viruses, the water should be chlorinated before being pumped into the distribution system. Chlorination will have the added benefit of removing potential bacterial contamination. Nearby farming activities may be the source of the bacteria.

Sodium levels were found to be as high as 79.9 milligram per liter (mg/L), which exceeds the Massachusetts Drinking Water Guideline (ORSG) of 20 mg/L. As this standard is a guideline, it is not intended as an enforceable standard. Elevated sodium levels, in all likelihood, originate largely from road-salting of Linebrook Road and perhaps the elementary-school parking lot.

Nitrate levels were found to be elevated, ranging from 4.3 to 5.6 mg/L, though below the MCL of 10 mg/L. Possible sources of nitrate include local farming and nearby septic-system discharges. In addition, chloride levels were found to be as high as 136 mg/L, though still below the SMCL of 250 mg/L. The elevated chloride levels are probably a result of road-salting.

Perfluorinated alkyl acids (PFAAs) were found at levels of up to 23-nanogram per liter (ng/L), which is below the ORSG of 70 ng/L. PFAAs are found in fire-fighting foams, and have been used to make carpets, clothing, fabrics for furniture, paper packaging for food, cookware and many other consumer products.

Levels of iron and manganese were found to be well below the SMCLs of 0.3 mg/L for iron and 0.05 mg/L for manganese. At the end of the pumping test, iron levels generally ranged from about 0.02 to 0.03 mg/L, and manganese levels were found to be no higher than 0.002 mg/L. Provided these levels remain unchanged over the long-term, the water will *not* require treatment to remove iron and manganese.

Evidence from the pumping test indicates a weak and indirect hydraulic link between Bull Brook and the Lynch wells under pumping conditions. AECOM estimates that a diversion of 0 to 18 gpm of streamflow might occur in August, depending on rainfall conditions and daily well-field pumping cycles. A diversion of 18 gpm is less than 10% of the August median streamflow of 216 gpm.

The pumping test also demonstrated that pumping of the Lynch Well affects water levels in a farmer's irrigation pond 600 feet to the north. We have recommended that the Town identify an adequate, alternative source of water for irrigation to maintain farming operations.

The New Source Final Report, the water-withdrawal permit amendment application (under the WMA) and the Environmental Notification Form (ENF) are currently under review by the regulatory agencies

Pending approval of the Lynch Site for new water supply, the Town intends to proceed with the design and construction of four new gravel-packed wells and pumping facilities. The pumping facilities would include chlorination to remove bacteria before the water is introduced into the distribution system. Alternatively, the water could be chlorinated at the existing Water Treatment Plant, if the Town chooses to pump the water there before introducing it into the distribution system.

Finally, the capital cost associated with the Lynch Well Site is approximately $2.96 M in July 2018 dollars, and the wells and pumping facilities could be operational within two years of project funding

The next steps for implementing Alternative 1 would include the following:

- Obtain approvals from the appropriate state regulatory agencies, i.e., DEP and MEPA;
- Investigate the source(s) of bacteria, and eliminate pathways for their introduction into the groundwater;
- Investigate the sources of nitrate, sodium, chloride and PFAAs, and develop a plan to reduce their levels in groundwater;
- Obtain local approvals, such as an Order of Conditions from the Conservation Commission;
- Identify an adequate, alternative source of water for irrigation to maintain farming operations; and
- Design wells and pumping facilities.

Alternative 1 Advantages:

- A new source of up to 0.73 MGD of drinking water that meets primary and secondary drinking water standards;
- Low levels of iron and manganese, that do not require filtration;
- The source could be used independent of the WTP, giving the Town a measure of operational flexibility and drought resiliency;
- The source requires only three-quarters of a mile of transmission main to connect to the existing distribution system.

Alternative 1 Disadvantages:

- Need to investigate and mitigate sources of bacteria, nitrate, sodium, chloride, and PFAAs;
- Need to identify an alternative source of irrigation water for local farming operations;
- Opposition by local watershed groups; and
- Above three circumstances could delay implementation.

5.2 Alternative 2: Browns Replacement Well

The use of Browns well is included as part of Alternatives 2a and 2b. Browns well is located on Route 1A/133 in Ipswich and was originally constructed in 1942. Refer to Figure 5-1 for the location. The first well was abandoned in 1954 when it was found to be pumping sand, and was replaced. The well built in 1954 is still in operation today, however, the well and associated pump station have reached their useful service life. The well pumps water directly into the distribution system and has historically been a productive well for the Town, but manganese levels have been increasing over the years. Recently manganese levels have ranged from 0.26 to 1.11mg/L. In 2016, AECOM conducted a test well investigation in an effort to identify a location for a replacement well. In a letter report dated March 31, 2016, AECOM recommended that a new gravel-packed replacement well be constructed 15 feet from the existing Browns well. Pumping tests indicated that the replacement well could be capable of producing up to 400 gpm. The work for the well replacement includes the following main components: construction a water main, gate valves and hydrant, electrical work, removal of trees and site restoration, removing and resetting chain link fence, abandoning the existing Browns Well, and constructing a new gravel-packed replacement well with a pitless well unit and pump. In addition, permits will need to be prepared and submitted, including a Notice of Intent and the DEP Replacement Well Permit application. Design, bidding, and construction phase engineering services would also be necessary. In the March 31, 2016 letter report on Browns Well, AECOM's concept-level opinion of cost for the design, permitting and construction of a replacement well and related pumping facilities was $575,000 in April 2016 dollars. Using the ENR CCI this estimate is equivalent to $625,000 in July 2018.

At the time of the test well investigation, the manganese levels in the test well samples were extremely low. However, the letter report noted that the manganese levels would likely rise to levels matching the existing Browns well once the well is operational. Therefore, the water from this well would need to be conveyed to the existing WTP for treatment or treated at a new greensand filtration plant (discussed below). Treatment options for the Browns well water were evaluated in the Ipswich Wells Action Plan for Manganese Control Report, dated June 2014. The report provided an evaluation of treatment options and locations including Alternative 2a: constructing a transmission main extending from the Well to the WTP; and Alternative 2b: constructing a greensand filtration plant at a nearby site. These two alternatives are discussed in more detail below.

5.2.1 Alternative 2a: Browns Replacement Well with Transmission Main to WTP

Alternative 2a includes replacing the existing 200 gpm well with a new 400 gpm replacement well and constructing a transmission main from the well to the existing WTP for treatment. The WTP is located a little more than a mile from the well. Refer to Figure 5-1 for the locations. The transmission main would be constructed in the right-of-way along High Street. High density polyethylene (HDPE) or PVC may be the most cost effective materials for this transmission main. HDPE and PVC are non-corrosive and can be installed relatively quickly when services and branches are not needed. Pipe material selection would be part of preliminary design. The preliminary design would also include an evaluation of whether an oxidation chemical such as potassium permanganate will be added at the well site, or if the water would be mixed with the raw water at the plant before chemical addition. The well water would most likely be conveyed to the pump station that is located upstream of the existing surface water treatment. This option should also include a blow-off line to the lagoons, as well as an option to discharge to the reservoir (pending regulatory approval). The concept level opinion of cost for the transmission main to the water treatment plant or to the reservoirs would be approximately $1 million in July 2018 dollars for the 1 mile long transmission main depending on the route taken.

The existing WTP is a conventional filtration plant built in 1986 with a capacity of approximately 2.5 MGD. The WTP process includes rapid mix, for coagulation, flocculation, settling, filtration, and disinfection. Treating the water from Browns Well may impact the treatment process by requiring an adjustment in coagulant chemical dosing, additional solids loading to the lagoons, and more frequent backwashing of the filters. However, the water quality of Browns well is similar to the reservoir water, so that the impact of adding Browns well to the WTP may be minimal.

To assess the impacts that the groundwater may have on the WTP process, AECOM reviewed the Long Term Plan for the Water Treatment Plant dated December 2012. The plan was prepared in response to a request by DEP to assess the reliability and consistency of the treatment systems due to their challenging source water quality. The plan included a description of bench top testing to assess various treatment processes that could effectively remove iron, manganese, and total organic carbon (TOC) that are present in the reservoir water. The report included a table which presents the iron and manganese concentrations for the Dow Brook, Bull Brook and a 50/50 Mix. Table 5-1 presents this data compared to values for Browns Well presented in the June 2014 Ipswich Wells Action Plan for Manganese Control.

Table 5-1. Surface Water Supply and Browns Well Iron and Manganese

Water Source	Total Iron (mg/L)	Total Manganese (mg/L)
Dow Brook[(1)]	0.58-1.54	1.2-1.8
Bull Brook[(1)]	0.54	0.28
50/50 Mix of Dow and Bull[(1)]	0.36-0.62	0.9-1.8
Browns Well[(2)]	0.02-0.28	0.26-1.11

Note 1. Data from Table 2-2 of the December 2012 Long Term Plan for the Water Treatment Plant Report. Data is for July, August and September 2009-2011

Note 2. Average values compiled from infrequent grab samples collected by the water department.

Comparing Browns well to the 50/50 mix of Dow and Bull Brook Reservoirs shows that the Browns well water has lower iron values than the 50/50 mix and similar manganese values. This comparison indicated that the well water may have limited impact on the WTP process. The December 2012 report recommended that potassium permanganate be added to the WTP process to aid in iron and manganese removal. Potassium permanganate may also be advantageous if Browns well is directed to the existing WTP.

The WTP has been operating over 30 years and therefore is most likely in need of an upgrade. An evaluation of this plant is recommended in the near future to assess improvements that could be made to better accommodate Browns well water.

The June 2014 report by AECOM did not recommended conveying Browns Well water directly to the WTP, but instead recommended constructing a greensand filtration plant. The concerns at that time were the construction of the 5,700 feet of transmission main piping along High Street, the potential for manganese settling in the pipe when the well is shut down, the concern that a new process would add an additional residuals load to existing lagoons, and partial loss of system redundancy. However, since that time, AECOM has successfully constructed a similar transmission main in Westborough, MA that conveys well water high in iron and manganese to a surface water treatment plant. The introduction of a groundwater with high iron and manganese concentrations has had minimal impact to the WTP process in Westborough. In addition, the existing Ipswich WTP is due for an upgrade and at that time any necessary improvements can be made. Also at the time of the 2014 report it was not noted that the iron and manganese concentrations in the well water and WTP raw water sources were similar.

In order to provide a cost for a WTP upgrade, an assessment of the existing WTP is needed. AECOM has recently undertaken two WTP assessments and subsequent upgrades projects. The costs of these two projects are presented as a reference of what a WTP upgrade project can cost. The upgrade in Tewksbury, MA of a 7 MGD WTP had a total project cost of approximately $14 million, and another upgrade in Westborough, MA of a 3.5 MGD WTP has a estimated total project cost of approximately $7 million. Both of these WTPs utilize conventional treatment like Ipswich, and neither of these WTPs had their treatment capacity expanded.

The next steps for implementing Alternative 2a include the following major items:

- Conduct jar testing to assess adjustments to chemical addition at the WTP.
- Prepare a layout of the transmission main from Browns well to the WTP.
- Begin permitting process for the replacement well.
- Conduct survey and borings along the transmission main route in preparation for design.
- Evaluate the existing WTP.

Alternative 2a Advantages:

- This would not require the construction of a separate treatment facility
- Additional staff would not be required.
- Land acquisition is not required
- Less permit requirements
- Existing WTP has adequate capacity
- An upgrade of the existing WTP is due, and any required modification could be implemented during the upgrade.
- An existing source is optimized

Alternative 2a Disadvantages

- Construction of the 5,700 foot transmission main in High Street.

- This option could impact the WTP process.
- Does not improve redundancy because another source of water supply would be treated through the WTP.

5.2.2 Alternative 2b. Brown's Replacement Well with Greensand Filtration Plant

Alternative 2b involves replacing the existing 200 gpm well with a 400 gpm well, which is the same as Alternative 2a. However, instead of pumping the water from the well to the WTP, this alternative involves constructing a new greensand filter plant to treat iron and manganese. As previously mentioned, this treatment option was evaluated in the Ipswich Wells Action Plan for Manganese Control Report dated June 2014. In this report, two different lots were evaluated as potential locations for the greensand filtration plant. The June 2014 report recommended that the plant be located at Lot 009, which is located directly across High Street from the Browns Well. The Browns Well water could be pumped to a facility located in this lot, and then directed back to High Street for connection to the existing 12-inch diameter main. It is also in close proximity to a sewer system which will allow for disposal of backwash residuals to the sewer, and will greatly minimize the amount of new piping needed to facilitate the treatment plant. Lot 009 is bounded along the back by wetlands, however, it appears preliminarily that there is enough available space to construct a greensand treatment facility. The facility would be approximately 50 ft x 50 ft , slab on-grade construction.

The concept-level opinion of costs for the greensand filtration plant and associated facilities was $4 million (June, 2014 dollars). Using the ENR CCI this estimate is equivalent to $4.5 million in July 2018 dollars. This cost includes the following main components:

The following elements are included in the estimate that was provided as part of that report:

- Greensand filter skid with face piping and controls. Skid is based on a duplex arrangement with (2) 7-ft diameter filters to operate at 5.2 gpm/ft^2. Proposal includes media, air scour blowers, and control panel.
- Site work and concrete work for a new 2500 SF pre-engineered building, perimeter fencing, paving, clearing, and landscaping. Allowance for stormwater controls and wetlands protection.
- Chemical feed system and containment for fluoride (to match existing), phosphate (for corrosion control), sodium hydroxide (for adjusting pH to promote Greensand operation), and sodium hypochlorite (for Greensand regeneration and for chlorine residual).
- Piping for raw water supply, backwash water supply from the distribution system, spent filter washwater force main to sewer, and filtered water connection to distribution system.
- Allowances for electrical connections, instrumentation, and transformer upgrade.
- 10,000 gallon collection tank for spent filter washwater, and a discharge pump and force main to dispose of washwater to sewer.

The next steps for implementing Alternative 2 include the following major items:

- Begin permitting process for the replacement well.
- Conduct survey and borings at Lot 009 in preparation for design.

The advantages and disadvantages for this site are listed below:

<u>Alternative 2b Advantages:</u>

- Locating the well water treatment plant at Lot 009 would require very minimal piping in High Street.
- The residuals could be directed to the sewer system in High Street
- The filter washwater could be partially supplied by the 14-inch or 12-inch diameter distribution system piping in High Street

- Because of the very limited friction head imparted by the well supply line to the new Greensand plant, the existing well pump head may potentially be adequate
- This stand-alone facility provides true redundancy to the water supply system as a whole
- An existing source is optimized

Alternative 2b Disadvantages

- Site is bounded in back by wetlands according to Mass GIS mapping. True wetlands survey would need to locate wetlands and subsequent wetlands buffer.
- Site is low-lying, with potential for high groundwater
- The new treatment facility would require additional staffing
- This option does not address any existing problems at the water treatment plant.

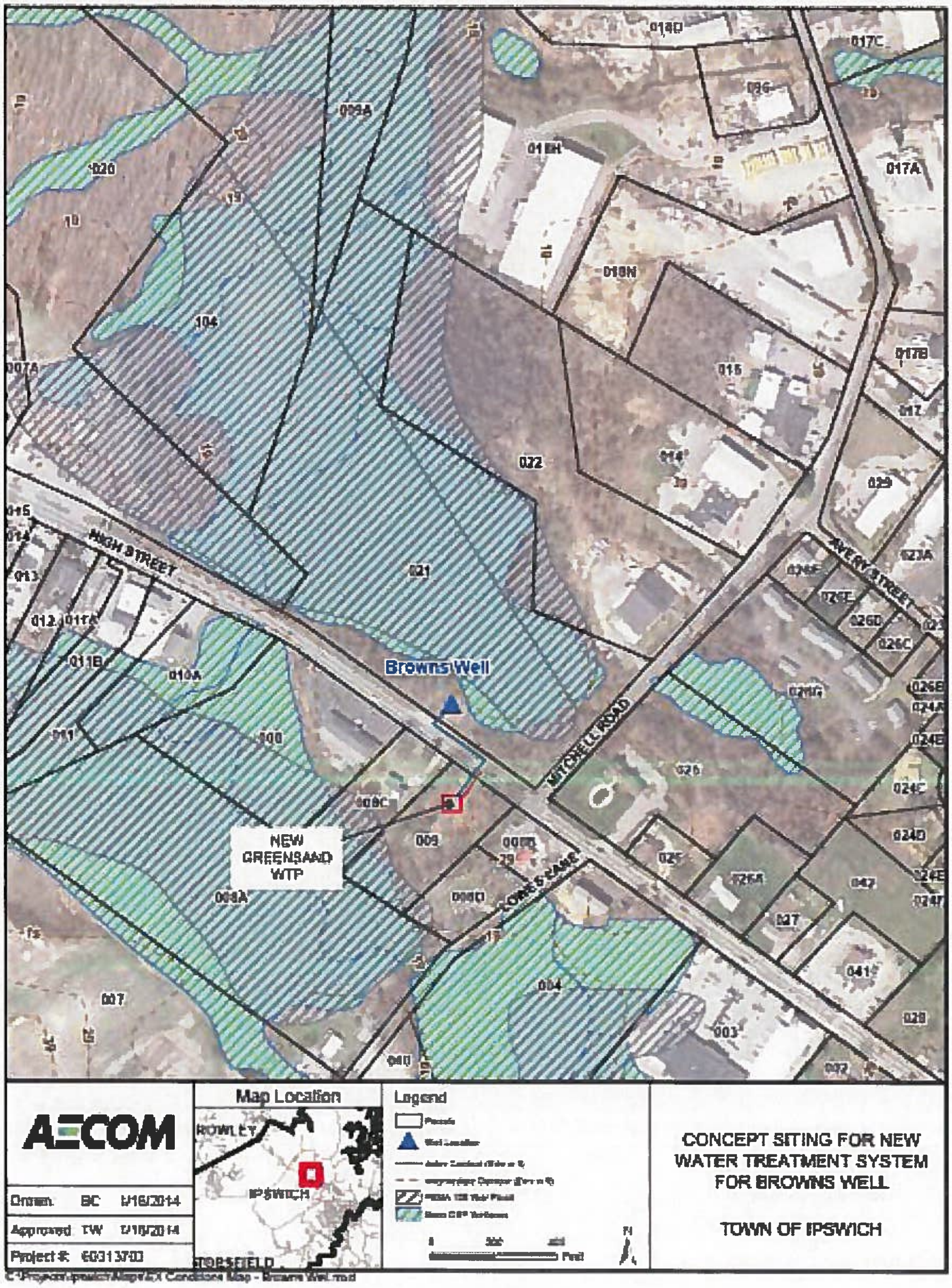


Figure 5-2. Browns Well Greensand Filtration Plan Location Plan

5.3 Alternative 3. Brackish Water Desalination

This alternative involves constructing a new BWRO plant with groundwater as the source of water supply. This alternative would allow the Town to become less dependent on water-supply sources in the Parker and Ipswich River watersheds. It would also provide drought resiliency and potentially provide water to surrounding communities. As mentioned in the text above, the BWRO process produces, as a byproduct, high-salinity brine that would need to be discharged to the ocean. The water from the groundwater wells would be pumped to the desalination plant, which is expected to be located on Town of Ipswich property near the existing WWTP. Figure 5-3 presents a location plan for the proposed desalination plant. For the purposes of this evaluation, it was assumed that the plant would have a finished water capacity of 3 mgd. Note that the source capacity would have to be higher than the finished water capacity to account for brine losses. BWRO plants of similar capacity have a footprint of approximately 175 feet by 75 feet. Space at the WWTP site appears to be sufficient to accommodate the BWRO desalination WTP.

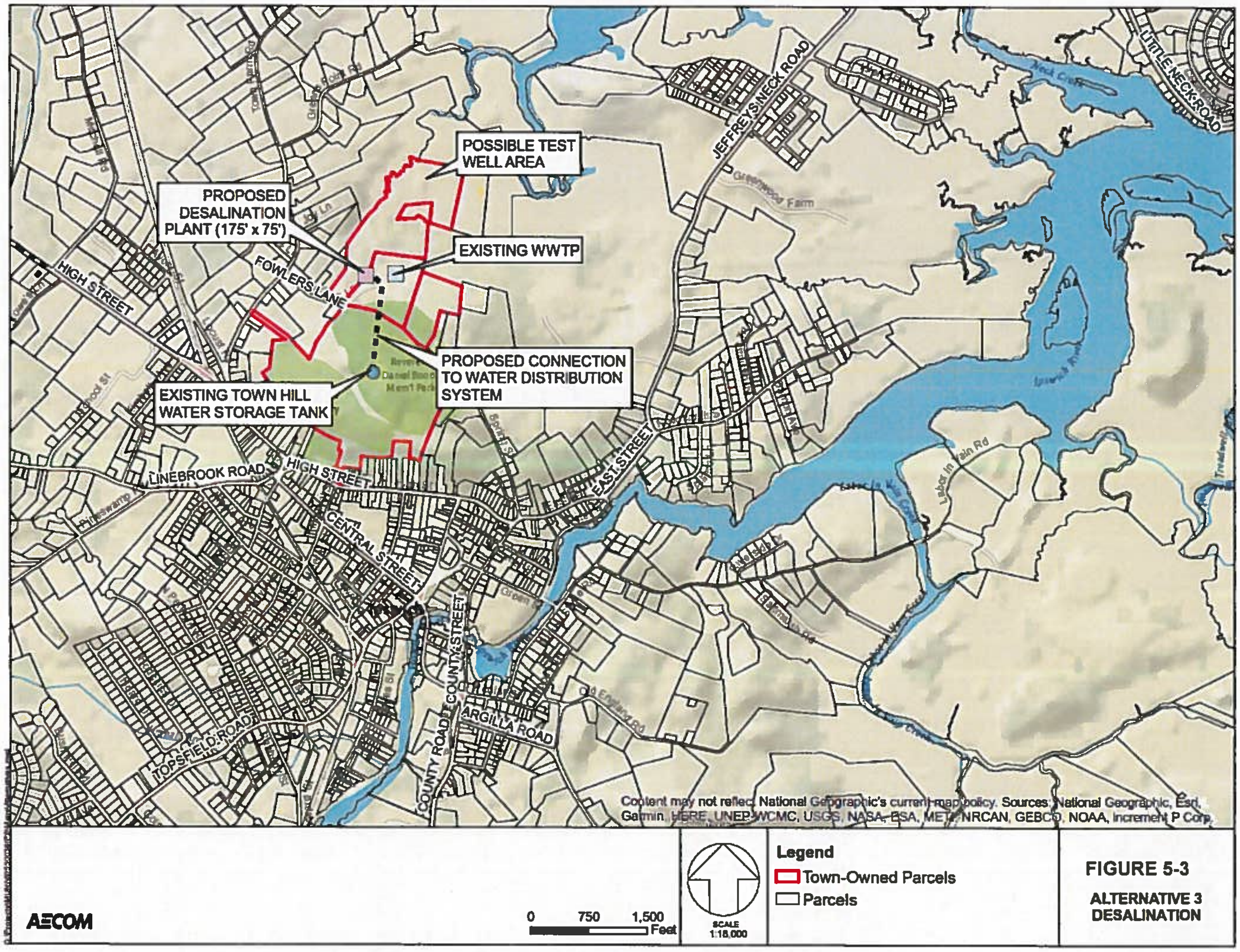


Figure 5-3. Alternative 3 Desalination

The concept level opinion of costs associated with the BWRO plant includes preliminary investigation expenses (such as survey and wetlands delineation, pumping tests, pilot testing of the water treatment process), design, permitting and construction. The scope of the options would have to be further refined to estimate costs. Based on previous experience with a facility in Florida, the opinion of construction cost of a 3 MGD desalination plant, six groundwater wells, and transmission mains is approximately $18,000,000. A 40% allowance was used to develop an opinion of cost for the topographic survey, borings, wetland delineation, design, permitting, bidding and construction. The concept level opinion of cost for the BWRO desalination plant is approximately $25,000,000.

As mentioned above, there are several factors that made this alternative worthy of further consideration:

- The Town owns land near the coast that may be underlain by an aquifer with a sufficient amount of fresh or brackish groundwater. Also, groundwater will likely have a more consistent and higher water quality than sea water. The enhanced water quality should eliminate a pretreatment process often required when sea water is used.
- The WWTP has an existing outfall that discharges to Greenwood Creek, which is a tidal creek. The brine that is created from the desalination process could be mixed with the WWTP effluent and be discharged through the same outfall. Mixing the two discharges will both dilute the brine and would add salinity to the existing WWTP discharge. In this way, the salinity of the discharge would be closer to the salinity of the tidal creek. Use of the existing outfall would eliminate the need to construct a new one for the desalination WTP.
- The proposed site is located close to the Town Hill water storage tank, which is located adjacent to the WWTP site on Town owned property. The treated water (drinking water) could be connected directly to the water distribution system at the tank, without obtaining any additional land or easements. Refer to Figure 5-3. The transmission main would need to be approximately 1,200 feet long.

The following investigations will need to be undertaken to evaluate the viability of Alternative 3:

1. Conduct a test-well investigation, geophysical surveys, water-quality testing, pumping tests and related hydrogeologic studies to assess the available capacity and the quality of the groundwater.
2. Conduct borings and survey at the proposed BWRO desalination plant site.
3. Once the results of the test well investigation are available assess the optimum capacity of the plant.
4. Conduct pilot study to refine design parameters

<u>Alternative 3 Advantages</u>

- The property for the desalination plant is already owned by the Town and it is located adjacent to the potential source water.
- The BWRO desalination plant could replace the existing WTP, as long as there is sufficient supply available.
- May not require an increase in the WMA authorizations for the Parker or Ipswich River basins. It could potentially reduce the amount of water withdrawn from the Parker River and Ipswich River watersheds. To clarify the implications of groundwater withdrawals at the coast, the WMA staff at DEP should be consulted.
- Improves drought resiliency.
- May be able to use existing outfall.

<u>Alternative 3 Disadvantages</u>

- Capacity of wells is not known and is critical to the viability of this alternative.

- Possible amendment to existing WWTP NPDES permit
- Permitting requirements would include: New Source Approval Permit, MEPA review process, a DEP Permit to Construct Wells/Pumping Facilities, and a DEP Permit to Construct a Water Treatment Plant Facility. A mandatory Environmental Impact Report (EIR) is required for any new withdrawal or expansion of 2.5 MGD for surface water or 1.5 MGD for groundwater.
- A new water treatment plant would need to be constructed.
- Operating costs for BWRO can be high, depending on the salinity
- Additional staffing for the plant would be required. However, if the existing water treatment plant could be removed from service, there would be no net increase of staff would be required.
- Extended implementation schedule due to required exploration, permitting, and construction activities

Recommendations from Section 5

Based on the evaluation of the three alternatives, it is recommended that the Town move forward with replacing Browns well and constructing a transmission main to the WTP. This option is the least expensive of the three alternatives recommended for further evaluation and will increase the water-supply capacity by 0.28 MGD (refer to Table 5-2).

Table 5-2. Recommended Alternatives Concept Level Opinion of Costs

Alternative No.	Concept Level Opinion of Costs	Capacity Increase (MGD)
Alternative No. 1: Lynch Well Site	$2,960,000	0.73
Alternative No. 2a: Browns Replacement Well with Transmission Main to WTP	$1,600,000	0.28
Alternative No. 2b: Browns Replacement Well with Greensand Filtration Plant	$5,125,000	0.28
Alternative No. 3: Desalination	$25,000,000	3.0

Increasing the Browns well capacity to 400 gpm (0.29 MGD) along with the addition of the Lynch Well Site, if it is successfully brought online (0.73MGD), will provide the additional water supply needed by the Town. The Browns Well has been a reliable water source for the Town and, with treatment for iron and manganese, it can continue to provide water. It is recommended that bench-scale jar-testing be conducted to evaluate the impacts Browns Well will have on the WTP process. Available water quality data indicates that the quality of the surface water from Dow Brook and Bull Brook Reservoirs is similar to the quality of Browns Well. It is also recommended that the Town move forward with test-well and related hydrogeologic investigations for the desalination alternative.

6 Summary and Conclusions

The report sections above provided information and findings related to the Town's drinking water supply system. Specifically, the following topics were discussed: 1) A history of the Town's system, 2) Historical and projected demands on the system, 3) Current capacity of existing drinking water supply sources, and 4) Potential new sources that can be used to meet current and future demands.

The most significant findings of AECOM's investigation can be summarized as follows:

Water Demand

- The Town's current average-day demand (ADD) is 1.01 MGD, and the current maximum-day demand (MDD) is 3.00 MGD. In 2040, the ADD is projected to be 1.39 MGD, and the MDD is projected to be 4.17 MGD
- In the last 25 years, the Town has managed to dramatically reduce demand (by more than 33%) by instituting monthly billing, a seasonal-rate structure for summertime usage, a water-use restriction bylaw and other measures, in spite of a growth in population.

Water Supply Capacity

- The reliable drought capacity of the reservoir system is 0.41 MGD, approximately 50 percent of the 0.8 MGD capacity of estimated in 1988.
- The total available storage in the Bull Brook and Dow Brook Reservoirs is 12.4 MG less than the storage computed in 1988. Every year for the last ten years, water-supply withdrawals from the reservoirs, during the summer and early fall, cause the reservoir levels to decline, with a consequent reduction in reservoir storage. This condition occurs despite the Town's efforts to manage and conserve water.
- The Town's reservoir system is undersized based on the watershed areas of the reservoir system.
- The capacity of 0.41 MGD represents the Firm Yield, which is defined as the water-supply capacity available during a drought of record. In this case, the drought of record occurred in 2016. The capacity of 0.8 MGD represents the Safe Yield, which was estimated based on a 1 in 20-year drought.
- The Town's water sources in the Ipswich River basin are limited by the Town's WMA Registration to 0.2 MGD.
- The Town's water sources in the Parker River basin are limited by the Town's WMA Permit/ Registration to 0.98 MGD
- The Town limits the Browns Well to about 0.2 MGD due to high levels of manganese, even though the well's authorized capacity is 0.49 MGD.
- Due to good water quality, the Town can pump the Mile Lane Well at its full capacity of 0.15 MGD.
- The Town's available water-supply capacity which when restricted is as low as 0.96 MGD during drought conditions is the sum of the reservoir-system Firm Yield (0.41 MGD), the WMA Registered withdrawal rates in the Ipswich River Basin (0.2 MGD), the current Brown's Well capacity (0.2 MGD) and the Mile Lane Well capacity (0.15 MGD).
- The current ADD exceeds the current capacity by 0.05 MGD. If the reservoir-system or WTP had to be taken out of operation for any reason, due to equipment failure, contaminated water or other reasons, the Town would need to take extreme measures to meet the ADD.
- With the foregoing in mind, the current supplies are insufficient, and new sources of supply must be identified.

Screening-Level Evaluation of Eight Alternatives for New Water Supply

AECOM and the Town developed a list of eight potential new or expanded sources to be evaluated at a screening level. AECOM evaluated each of the eight alternatives using the following screening criteria: potential capacity gained, technical feasibility, permitting requirements, stakeholder concerns, treatment requirements, additional staffing needs, concept-level opinions of cost, and schedule for implementation. During the screening process, we inevitably had to make certain assumptions and judgements where information on each of the screening criteria was incomplete. AECOM worked closely with the Town, especially where information was scarce or where the Town had considered certain options in the past. The eight options included:

1. New Well Fields
2. Reservoir Expansion - Raising Existing Dams
3. Reservoir Expansion - Excavating Around Reservoirs/Removing Sediment
4. Reservoir Expansion - Building New Upstream Dams
5. Reservoir Expansion- Building Storage Tanks
6. Desalination
7. Wastewater Reuse
8. Interconnections with Surrounding Communities

As a result of the screening-level evaluation, the New Well Fields and Desalination options proved to be the most advantageous, and the remaining options were eliminated from further consideration. The reasons for eliminating certain options varied. Some of the major reasons include:

- The reservoir-expansion options would add only 0.08 MGD in capacity;
- Wastewater reuse could be viewed as a "toilet-to-tap" solution and would only supply water seasonally; permitting efforts and costs could be significant;
- Interconnections with neighboring communities, needed especially during dry weather, may not be viable as dry weather could likely affect those communities' ability to supply water.

Three Most Advantageous Options For New Supply

AECOM met with the Town in late November 2018 to present the results of the screening-level evaluation of potential water-supply options. After a review and discussion of the alternatives, we reached a consensus on the following three most favorable options for further investigation:

1. New Lynch Well Site
2. Browns Replacement Well
    a. Browns Replacement Well with Transmission Main to the WTP, or
    b. Browns Replacement Well with a new Greensand Filtration Plant
3. Desalination (brackish groundwater).

Based on the detailed evaluation of the three alternatives, the Town is moving forward with the Lynch Well site. During the course of AECOM's water-supply and demand investigation, the Town was separately testing the Lynch Well Site for new groundwater supply, under the DEP New Source Approval process. As of January 2019, the Lynch Well Site is awaiting DEP approval. Should DEP approve the Lynch Site, it could provide up to 0.73 MGD of new water-supply capacity.

In addition to the Lynch Well site, AECOM also recommends that the Town move forward with the replacement of the Browns well and constructing a transmission main extending from the well to the WTP.

This option is the least expensive of the remaining alternatives recommended for further evaluation, and will increase the water-supply capacity by 0.29 MGD. The Browns Well has been a reliable water source for the Town and with treatment for iron and manganese it can continue to provide water. We recommend that bench-scale jar-testing be conducted to evaluate the impacts Browns Well will have on the WTP process. Available water quality data indicates that the quality of the surface water from Dow Brook and Bull Brook Reservoirs is similar to the quality of Browns Well.

We also recommended that the Town move forward with test-well and related hydrogeologic investigations for the desalination alternative. The desalination alternative has many attractive features. If a brackish groundwater source of 3 MGD can be identified, the Town could conceivably abandon all its existing sources. In addition, the groundwater sources and desalination plant would be located at the site of the Town's existing WWTF. Brine generated from desalination could be combined with the wastewater effluent and discharged to the existing outfall at Greenwood Creek. Treated water of drinking water quality would be piped 1,200 feet into the Town Hill water storage tank and from there into the water-distribution system.

6.1.1 Reference Documents

Dow Brook Reservoir Bathymetric Survey, CR Environmental, Inc. June 2018

Bull Brook Reservoir Bathymetric Survey, CR Environmental, Inc. May 2018

Parker River Basin Water Management Act Registration, December 31, 2017

Dow Brook Reservoir Dam Phase 1 Inspection/Evaluation, Haley & Aldrich August 29, 2017

Replacement Well Investigation Browns Well Letter Report, AECOM, March 31, 2016

Bull Brook Reservoir Dam Phase 1 Inspection/Evaluation, Haley & Aldrich November 17, 2015

Ipswich Wells Action Plan for Manganese Control Final Report, AECOM, June 2014

Long Term Plan Ipswich Water Treatment Plant, Wright Pierce, December 2012

Refinement and Evaluation of the Massachusetts Firm-Yield Estimator Model Version 2.0, USGS, October 2011

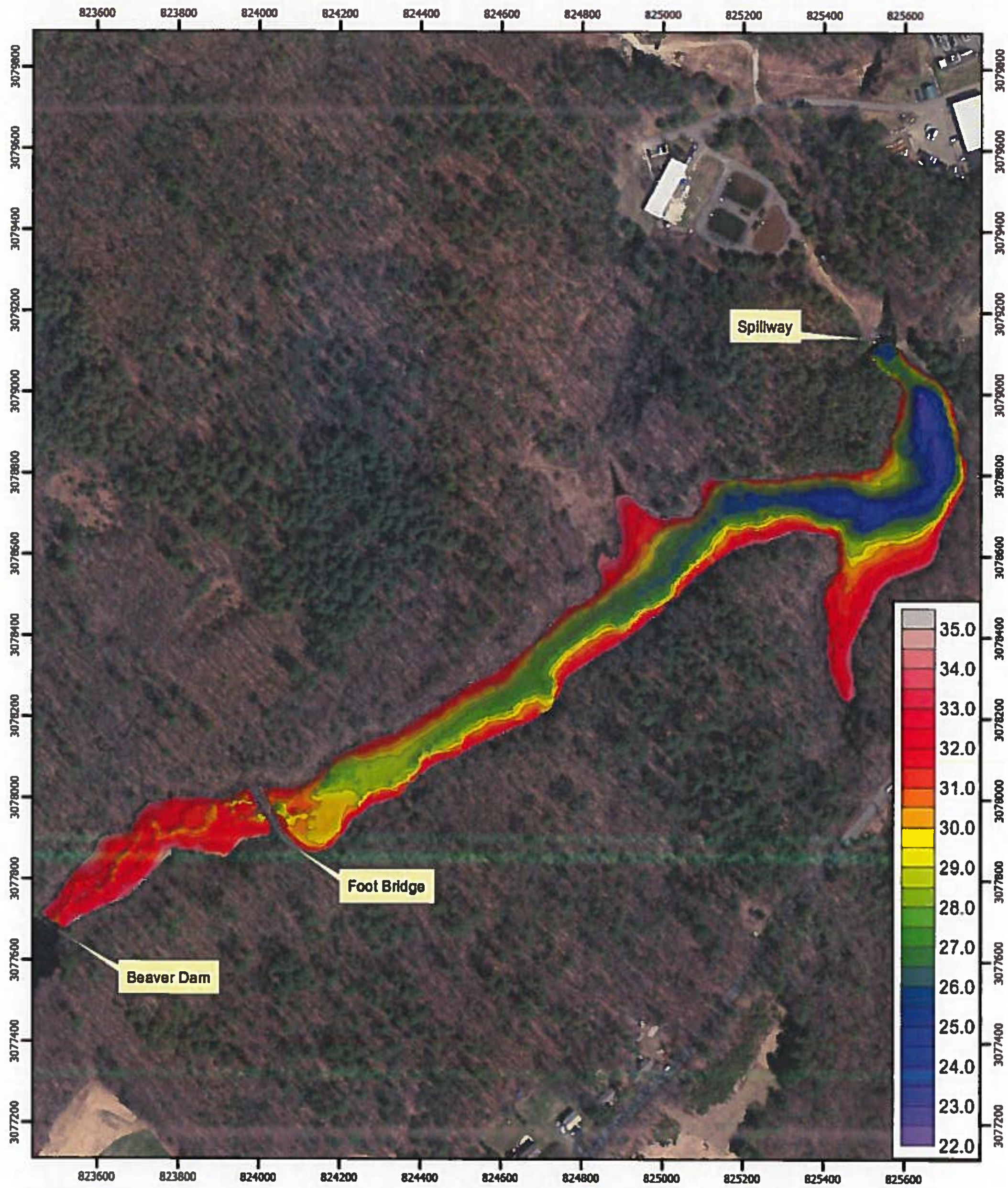
Ipswich River Basin Water Management Act Registration, 2007

Ipswich, MA Feasibility Study for Treatment Facility, Camp Dresser & McKee, January 1984

Ipswich Public Water Supply Yesterday and Today, presentation at Ipswich Museum, January 8, 2018, by J. Engle

Email correspondence between AECOM and Duane Levangie from December 12 to December 17, 2018

Appendix A Bathymetric Survey



BULL BROOK RESERVOIR BATHYMETRY
1.0-Foot NAVD88 Elevations
Ipswich, Massachusetts

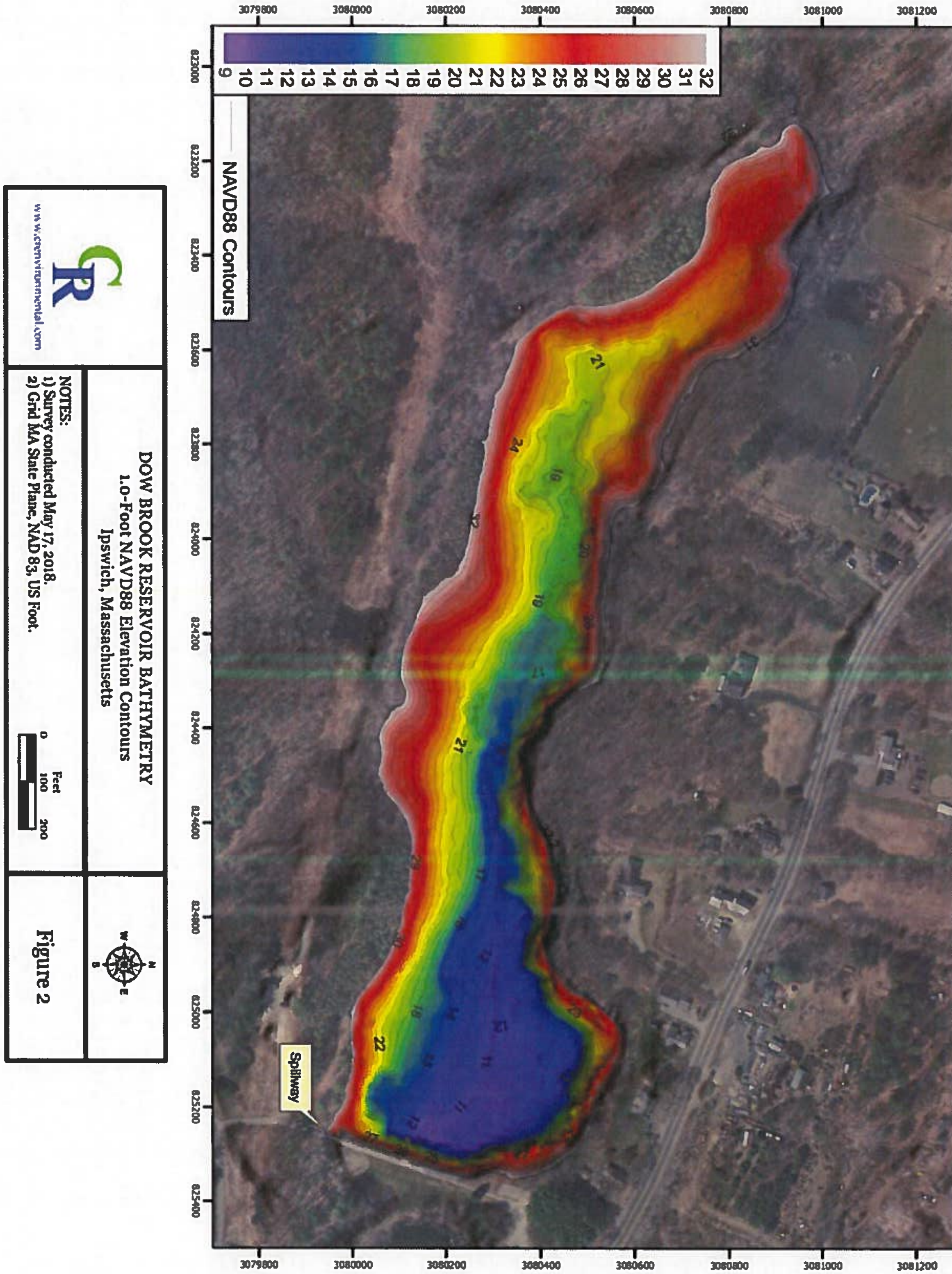
www.crenvironmental.com

NOTES:
1) Survey conducted April 11, 2018.
2) Grid MA State Plane, NAD 83, US Foot.

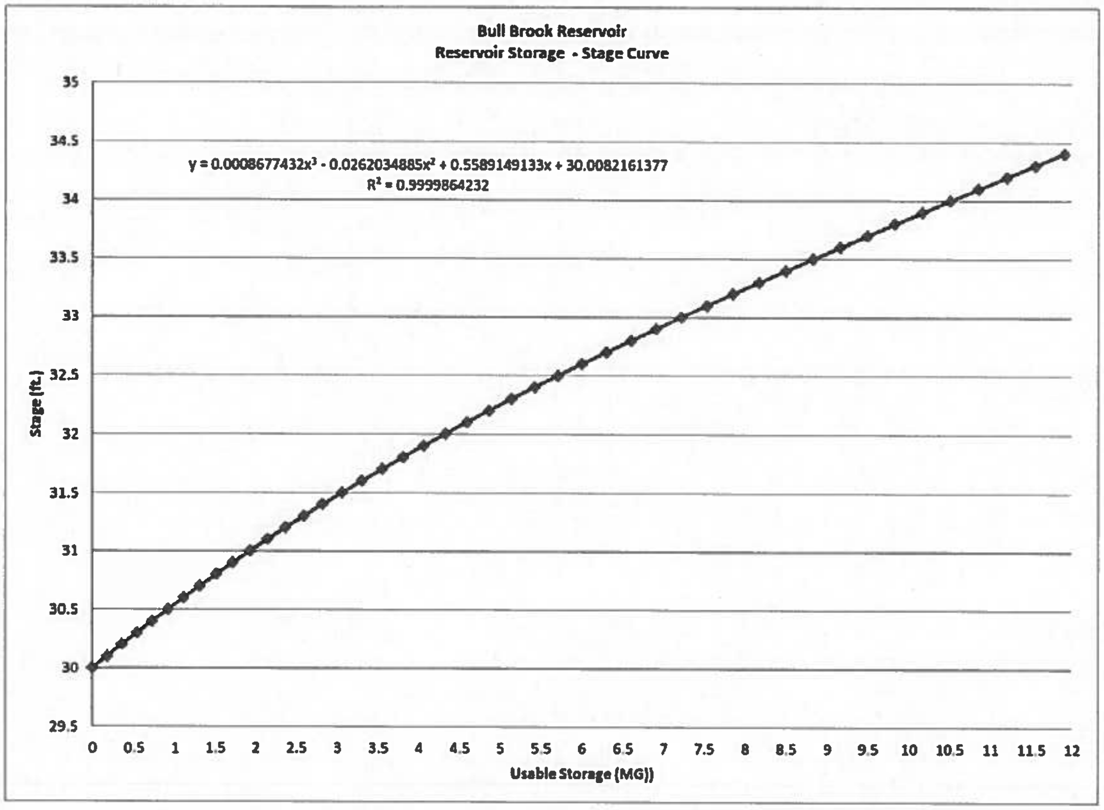
Feet
0 200 400

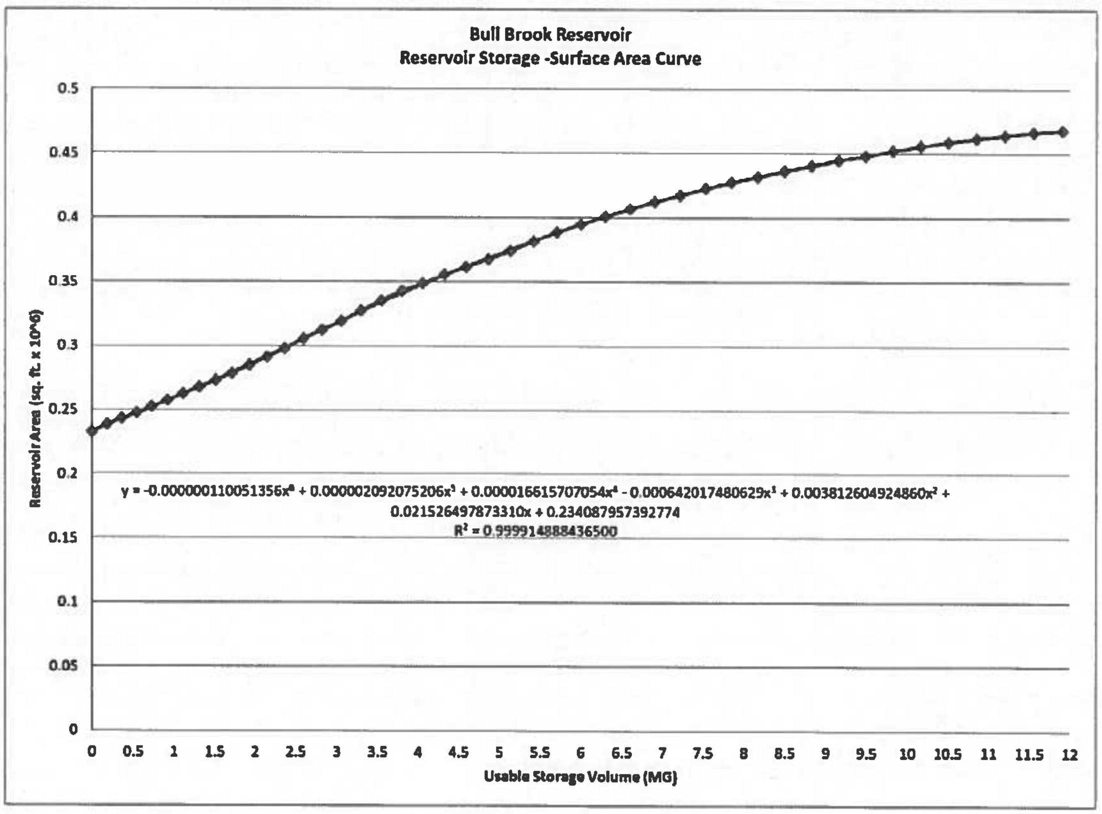
N W E S

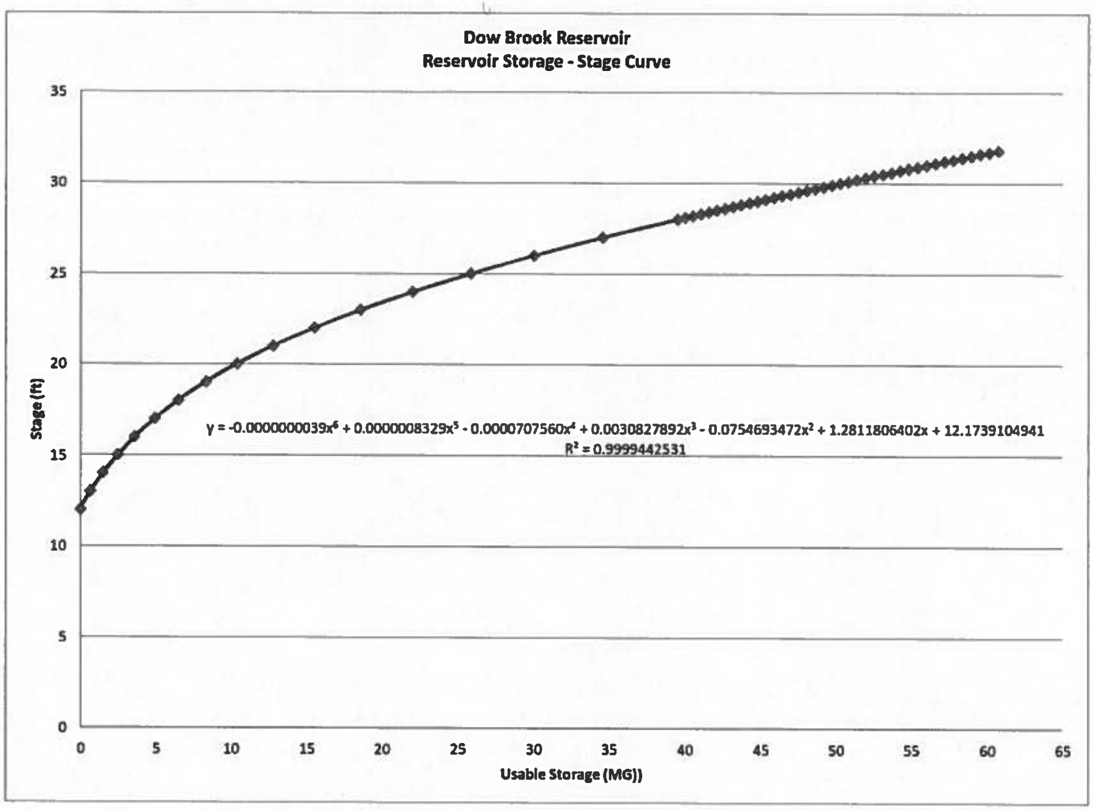
Figure 2

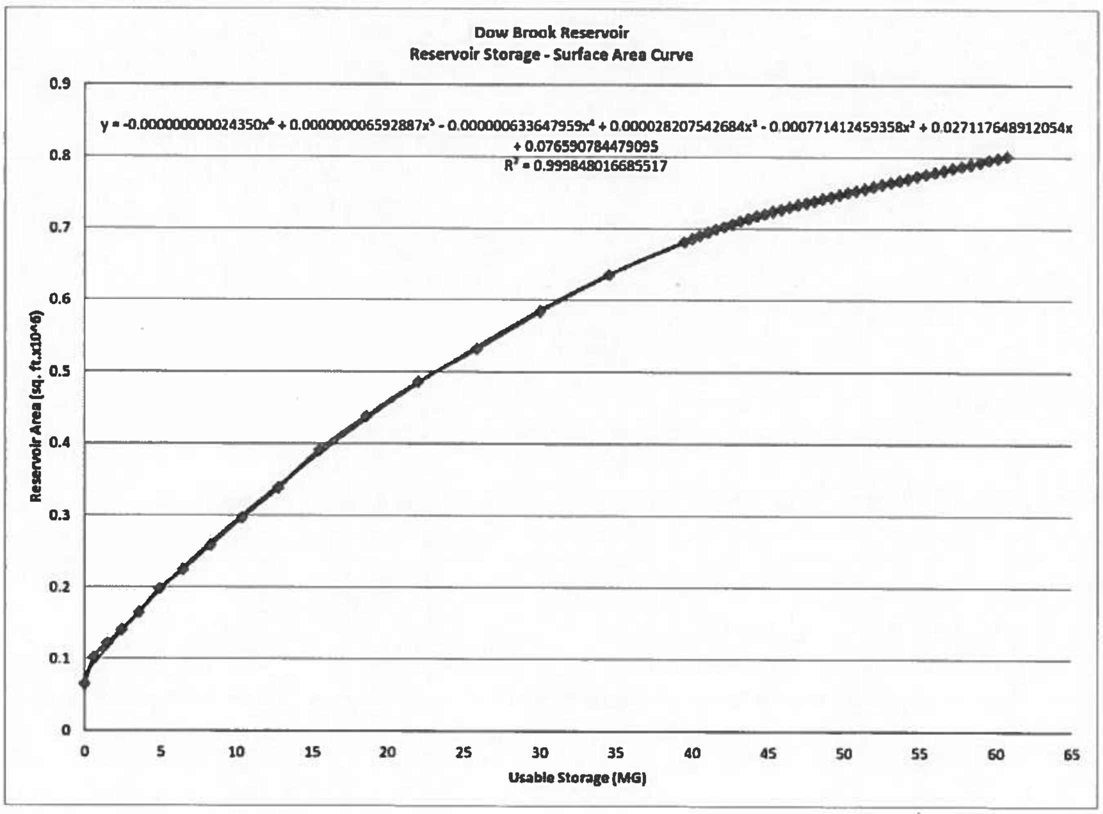

DOW BROOK RESERVOIR BATHYMETRY
1.0-Foot NAVD88 Elevation Contours
Ipswich, Massachusetts
NOTES:
1) Survey conducted May 17, 2018.
2) Grid MA State Plane, NAD 83, US Foot.
Feet
0 100 200
Figure 2
www.crenvironmental.com
NAVD88 Contours
Spillway

Appendix B Firm Yield Curves


Bull Brook Reservoir
Reservoir Storage - Stage Curve
y = 0.0008677432x³ - 0.0262034885x² + 0.5589149133x + 30.0082161377
R² = 0.9999864232
Stage (ft.)
35
34.5
34
33.5
33
32.5
32
31.5
31
30.5
30
29.5
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12
Usable Storage (MG))


Bull Brook Reservoir
Reservoir Storage -Surface Area Curve
y = -0.000000110051356x⁶ + 0.000002092075206x⁵ + 0.000016615707054x⁴ - 0.000642017480629x³ + 0.003812604924860x² +
0.021526497873310x + 0.234087957392774
R² = 0.999914888436500
Reservoir Area (sq. ft. x 10^6)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12
Usable Storage Volume (MG)


Dow Brook Reservoir
Reservoir Storage - Stage Curve
y = -0.0000000039x⁶ + 0.0000008329x⁵ - 0.0000707560x⁴ + 0.0030827892x³ - 0.0754693472x² + 1.2811806402x + 12.1739104941
R² = 0.9999442531
Stage (ft)
0
5
10
15
20
25
30
35
0
5
10
15
20
25
30
35
40
45
50
55
60
65
Usable Storage (MG))


Dow Brook Reservoir
Reservoir Storage - Surface Area Curve
y = -0.00000000024350x⁶ + 0.00000006592887x⁵ - 0.000000633647959x⁴ + 0.000028207542684x³ - 0.000771412459358x² + 0.027117648912054x
+ 0.076590784479095
R² = 0.999848016685517
Reservoir Area (sq. ft.x10^6)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
5
10
15
20
25
30
35
40
45
50
55
60
65
Usable Storage (MG)